# Lake Couchiching
## Environmental Quality
## 1997

## Volume I:
## Main Findings

WSA
Water Systems Analysts

Ministry of the
Environment
Ontario

ISBN 0-7778-8497-6

(VOL.I) 0-7778-8498-4

# LAKE COUCHICHING ENVIRONMENTAL QUALITY - 1997

## VOLUME I - MAIN FINDINGS

April 2000

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PIBS 3736e

# Lake Couchiching Environmental Quality - 1997

## Volume I - Main Findings

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April 2000

# SUMMARY

## Introduction

Lake Couchiching is part of the Trent-Severn Waterway, connecting Lake Ontario with Georgian Bay. Water enters the lake from Lake Simcoe at Atherley Narrows and flows north. Lake Couchiching (latitudes 44°36' to 44°45' N; longitudes 79°20' to 79°25' W) has a surface area of about 33.75 km$^2$ (12,100 acres) and has 45 km (28 mi) of shoreline. One large island (Chiefs Island) and several smaller ones (Horseshoe, Heron and Garnet) comprise a land area of 0.84 km$^2$, with a total shoreline length of 14.6 km. The lake is shallow, with a maximum depth of 12 m (39 feet) and an average depth of 6 m (20 feet).

In response to concerns that the environmental quality of Lake Couchiching is under pressure from increasing recreational uses and development along its shores, this study was conducted to:

(i) establish a baseline database with respect to the lake's limnology, water, sediment and biological quality,
(ii) define the existing aquatic environmental quality and trophic status of Lake Couchiching (i.e., at the present level of development); and ,
(iii) develop recommendations concerning possible impacts associated with future development.

Based on these overall objectives, this study characterized water and sediment quality at several locations in Lake Couchiching. This study also characterized bacteria, phytoplankton, zooplankton, macroflora (macroalgae and macrophytes) and benthic macroinvertebrate communities. This study did not attempt to characterize the condition of fish populations in Lake Couchiching since the local Ministry of Natural Resources offices routinely update that information. The biological communities (phytoplankton, zooplankton, macroflora, and benthos) that are characterized in this study are however, capable of being used as early warning indicators of potential effects on fish populations in the lake. Surveys were conducted throughout the ice-free period in 1997.

## Methods

Water quality was characterized every two weeks at four mid-lake stations, while samples were collected during late spring and mid summer at 17 stations located around the periphery of the lake. At the two deepest points in the lake (Stations 5 and 15), water samples were collected both 1 m below the surface, and 1 m off bottom (1 MOB). At all four mid-lake stations, dissolved oxygen and temperature profiles were determined to further examine the effect the sediments might have on dissolved oxygen concentrations. Surficial sediments and sediment cores were collected and examined for metals and organic compounds. Sediment cores collected historical sediments deposited in the lake. They thus provide a good baseline against which to judge current sediment contaminant concentrations. Zooplankton at the four mid-lake stations were counted and identified to species. Zebra mussels veliger larvae were also counted. Surveys of macroflora (plants/algae) and benthic invertebrates were made at the 21 stations.

## Highlights

### Basic Chemistry and Nutrients Status

Lake Couchiching is a basic, hardwater lake with high alkalinity (greater than 100 mg/L) and pH (above 8). The lake is therefore not susceptible to the effects of acidic precipitation. Based on nutrient chemistry, the lake is oligotrophic. Primary production in the lake is limited by phosphorus which was present at low concentrations. Where phosphorus is the limiting nutrient, the Ontario Ministry of Environment recommends that total phosphorus concentrations be kept below 0.020 mg/L to avoid nuisance growths of algae. Total phosphorus concentrations in the lake were typically less than 0.014 mg/L suggesting that nutrient concentrations are not high enough to cause nuisance growths of algae.

Concentrations of chlorophyll *a* in Lake Couchiching were low. Among the mid-lake stations, chlorophyll *a* concentrations ranged from 0.5 to 2.6 $\mu$g/L. Concentrations peaked in mid-July and were lowest through late August and September. Lakes with summer average chlorophyll *a* concentrations of between 2 and 5 $\mu$g/L are typically classified as mesotrophic. Based on the observed chlorophyll *a* concentrations, Lake Couchiching can be classified as oligotrophic to slightly mesotrophic.

Lake clarity can also be used to characterize nutrient status. Water clarity was measured by Secchi disc depths. In general, Lake Couchiching has good clarity: Secchi discs were visible on the bottom at all shallow nearshore stations. At mid lake, Secchi depths varied between 4 and 7 m and had increased from 1977. Lakes with a Secchi depths greater than 5 m are typically considered oligotrophic. Based on Secchi depth readings, Lake Couchiching can, therefore, be considered oligotrophic.

### Bacteria

Bacterial counts were determined from water samples collected at each of the 21 stations during June and July. These samples were not in the vicinity of beach areas. Bacteria were detected infrequently and at low densities. The highest density or concentration of the indicator *Escherichia coli*, 36 organisms per 100 ml at Station 1 near Cedar Island, was well below the Provincial Water Quality Objective (PWQO) of 100 organisms per 100 ml for the protection of recreational water users. Faecal *Streptococcus* was detected at a maximum density of 18 , again at Station 1 near Cedar Point. There is currently no PWQO for numbers of faecal streptococci . The pathogen *Pseudomonas aeruginosa* was not detected in any of the samples. Based on these data, there is no apparent risk of infection by swimming in Lake Couchiching.

### Taste and Odour Problems

Residents of Orillia have complained about poor taste and odour of municipal water supplies originating from Lake Couchiching. Taste and odour problems have been attributed to two compounds (geosmin, or 1,10-trans-dimethyl-trans-9-decalol, and 2-MIB or 2-methylisoborneol) that originate primarily in algae. Previous work had shown that algal densities in the water column of Lake Couchiching are below thresholds that would cause taste and odour problems. It has been suggested, however, that green and blue-green algae that reside on the bottom of the lake may be partially responsible for the poor taste and odour. Indirectly, the introduction of zebra mussels to the lake may be responsible for the poor taste and odour. Where zebra mussels colonize, densities of benthic algae have been shown to increase. Zebra mussels have colonized virtually every location within the lake and this survey did document areas with extensive growths of algae.

**Metals**

Slices of historic sediments indicated that arsenic and some metals (e.g., lead, zinc, mercury, cadmium, copper) have increased in the lake's surficial sediments. Metal levels in water and sediment are, however, still at safe levels for aquatic life. Even though metal levels were low, there is still evidence that mercury is biologically available and biomagnifies in the aquatic food chain. Routine monitoring by the Ontario Ministry of the Environment shows that mercury levels in large smallmouth bass, largemouth bass, northern pike, walleye and yellow perch are elevated, and that there are consumption restrictions.

**Organic Contaminants**

Relative to concentrations in historical sediments, concentrations of oil and grease were slightly elevated in surficial sediments, especially in the vicinity of Orillia (Stations 1 to 4). However, since no petroleum hydrocarbons were detected, the oil and grease found near Orillia would appear to be from natural sources such as lipids and fats resulting from decomposing plant and animal matter. Atrazine was detected at "trace" amounts (i.e., less than 150 ng/L) in over half of the water samples, with most of the detections occurring along the western shore. Atrazine concentrations were less than levels required to pose ecological or human health risks. Atrazine is a herbicide used in the cultivation of corn, and is non-persistent in aquatic environments.

Polycyclic aromatic hydrocarbons (PAHs) were detected at low concentrations in a few of the Lake Couchiching surficial sediment samples. PAHs were detected primarily in the south-west end of the lake near Orillia. With one minor exception, concentrations of the individual compounds, as well as total PAHs were below the respective Provincial Sediment Quality Low Effect Levels (i.e., concentrations at which there is the potential to affect 5% of the sediment-dwelling biota). Persistent organic contaminants including polychlorinated biphenyls (PCBs), organochlorine pesticides, phenoxy acid herbicides, chlorinated phenols, and chlorinated aliphatics and aromatics were not detected in any of the surface sediment samples. Organic contaminants in Lake Couchiching, therefore do not pose ecological or human health risks.

**Phytoplankton (Algae)**

The phytoplankton were represented by 54 genera. Communities were generally similar among the mid-lake stations, reflecting relatively homogeneous water quality across the lake. At all stations, biovolumes of phytoplankton were low ($<350{,}000\ \mu m^3$/ml). No nuisance levels of algae were observed. The dominant algae in Lake Couchiching were those typical of oligotrophic (low nutrient) conditions including the diatom *Cyclotella* sp.

**Zooplankton**

Zooplankton were represented by 15 species. Zebra mussel veliger larvae were also recorded in the plankton. The zooplankton were composed primarily of calanoid and cyclopoid copepods and non-daphnid cladocerans (*Bosmina longirostris*). The zooplankton community was also characteristic of oligotrophic conditions with a low biomass ranging between 5 and 37 mg/m$^3$ and peaking at only 80 mg/m$^3$. In this survey, zebra mussel veliger larvae were first observed on June 17. On July 9, veliger larvae exceeded the biomass of other zooplankters. Of a total zooplankton biomass of about 18 mg/m$^3$, veligers constituted about 14 mg/m$^3$ of the total, with a density of over 16,000 veligers per m$^3$. Through the remainder of the summer, veligers gradually fell in importance from about 40% of the zooplankton biomass to about 20% by the end of August. Veliger densities were strongly associated with water clarity, with peak densities occurring during the spring clear-water phase evident through June and July.

### Macroflora

In Lake Couchiching, the macroalga *Chara* was the single most dominant form. It was a dominant bottom feature at all shallow-water (< 7 m) stations, but was absent at the two deepest stations (5, 15). When found, beds of *Chara* were up to 50 cm high. *Vallisneria americana*, (tape grass, wild celery), *Utricularia vulgaris* (bladderwort), *Najas flexilis* (bushy pondweed) and *Potamogeton richardsonii* (Richardsons pondweed) were also present at many stations. Broadleaf forms of *Potamogeton* (*P. amplifolius*), *Elodea canadensis* (common waterweed) and *Myriophyllum* sp. (Eurasian Water Milfoil) were found at a few stations each.

The filamentous green alga *Spirogyra* was common in the south portion of the lake. This plant was growing on (fouling) the aquatic macrophytes and *Chara sp.* beds. Large billowy clouds of this alga were present on the sandy substrates near the breakwalls around the marina at Orillia and in the bay areas between the marina and the Narrows near the incoming flows from Lake Simcoe. Previous studies of plants did not document significant growths of this alga. Large growths of filamentous green algae can result in water quality problems, including loss of recreational potential (i.e., swimming) and loss of habitat for fish and wildlife (fouling of plant beds and bottom substrate). Large amounts of *Spirogyra* and other filamentous green algae have the potential to reduce dissolved oxygen levels during the night.

In 1972, *Myriophyllum* was the most dominant (79% of stations) and abundant plant form. In 1997, *Myriophyllum* was not abundant or prevalent, being found at only a single station (19) at the inflow of Lake Couchiching. In 1972, the species of *Myriophyllum* was probably *M. spicatum* (or Eurasian Water Milfoil). This exotic plant clogged several lakes in Southern Ontario with growths impeding the operation of water craft. The decline in abundance of *Myriophyllum* in Lake Couchiching is not unusual. Since the early 1970s, *Myriophyllum* has declined or disappeared from other lakes in Ontario and the north western United States.

### Benthic Communities

The benthic community was represented by 96 taxa from 22 major invertebrate taxonomic groups. In general, sediments at most stations contained the common amphipod *Hyalella azteca*, a good variety of chironomids (midges), the mayfly *Caenis punctata*, a few Leptoceridae (caddisflies), an assortment of gastropod molluscs (snails) and a large number of the bivalve mollusc *Dreissena* *polymorpha* (i.e., zebra mussels). The generally uniform substrate of silty sand, with a high mollusc shell content and dense mat of the aquatic plant *Chara* was probably responsible for the generally uniform benthos. Total numbers of benthos (including zebra mussels) ranged from just over 7,000 $m^{-2}$ to just under 100,000 $m^{-2}$, while the number of taxa per sample ranged from 14 to 28.

Adult zebra mussels were found at all stations in abundances ranging as high as 60,000 $m^{-2}$. Most of these zebra mussels were associated with *Chara,* actually being attached to the macroalga. So far, abundances of zebra mussels in Lake Couchiching are not extraordinary. Zebra mussel populations have exceeded 200,000 $m^{-2}$ on hard substrate in Lake Erie, but are typically lower (10,000 $m^{-2}$) on soft substrate.

The date of entry of zebra mussels into the lake has not been confirmed. However, some of the limnological characteristics of the lake may already reflect the effect of zebra mussels. For example, an increase in water clarity from 1977 to 1997 could be attributed, in part, to the introduction of zebra mussels. To document the arrival of zebra mussels, the Ontario Ministry of Natural Resources has conducted surveys of zebra mussel veliger larvae (the free-swimming stage) for several years but has not published the findings of those studies.

The benthic fauna of Lake Couchiching generally reflected a slightly mesotrophic condition. The presence of Orthocladiinae chironomids (especially *Epoicocladius*), and the Tanytarsini chironomids *Stempellina* and *Zavreliella* suggest relatively high water quality since these taxa are sensitive to eutrophication. The most dominant chironomids included *Chironomus*, *Dicrotendipes, Paratendipes, Tanytarsus*, and *Procladius*. All but *Tanytarsus* are reasonably tolerant of oxygen deficits. Finally, mesotrophy can be assumed based on the abundances of organisms at all stations. Typically, oligotrophic lakes can support only up to about 2,000 benthic organisms $m^{-2}$. In Lake Couchiching, numbers were generally in excess of about 20,000 $m^{-2}$ suggesting at least a slightly mesotrophic condition.

The composition of benthic invertebrate communities in the lake was relatively homogeneous, with a few exceptions. Deep-water communities (Stations 5 and 15) did have more fingernail clams (*Pisidium*), snails (*Helisoma anceps*) and phantom midges (*Chaoborus*) than did shallower sites. Station 19 near the inflow from Lake Simcoe had larger populations of aquatic sowbugs, and valvatid snails than other locations. Fauna from this station may reflect the cooler waters from Lake Simcoe. Finally, Stations 16 (near the YMCA discharge at Geneva Park) and 18 (at the mouth of Sucker Creek , into which Fern Resort discharges) had large populations of midge larvae (Chironomidae) indicating moderate impairment.

### Trophic Status

The lake can be classified as either oligotrophic or moderately mesotrophic based on the good water clarity, low nutrient concentrations, and a suite of organisms (phytoplankton, zooplankton, benthos) that are typically associated with oligotrophic and slightly mesotrophic conditions. Oligotrophic lakes are the most desirable from a recreational standpoint because of the high clarity. They also tend to support large sport fish because oxygen concentrations are high throughout the year, even in deep water. Mesotrophic lakes are characterized by moderate growth of algae and aquatic plants. They are suitable for the pursuit of water-oriented recreational activities but have the potential to develop periodic algal blooms.

**Recommendations**

The third objective of this report is to provide recommendations concerning possible impacts associated with future development. With increasing development, there is the potential for alterations in water quality to occur. Some of the more significant sources of water quality impairment include:

i) soil erosion and sedimentation from construction activities
ii) increased contaminant, bacterial, and suspended solids loadings from storm-water runoff
iii) increased phosphorus loadings from future development (municipal sewage)
iv) streambank erosion in new developments
v) introduction of exotic species
vi) loss of aquatic habitat through shoreline development

Based on the predicted impacts of development and on the results of the survey, the following recommendations are made.

**Recommendation 1: Further confirmation and investigation of sites where impairment was demonstrated.**

Biological impairment was evident at Station 16 and at Station 18. Further confirmation and investigation of impairment at these two locations by the Ministry of the Environment is warranted.

**Recommendation 2: Implement appropriate management practices to minimize water quality impairment**

Water quality impairment from development can be minimized through proper planning, education and mitigation. In this regard, the Ministry of the Environment is conducting meetings with Municipalities, conservation authorities and consultants in Simcoe County.

**Recommendation 3: Develop a monitoring program to track long-term changes due to the trophic status of the lake.**

In order to assist area municipalities in making prudent planning decisions, the Ministry of the Environment will conduct periodic biological and chemical monitoring in Lake Couchiching.

## ACKNOWLEDGEMENTS

The Project Managers for this study were Bruce Hawkins and Peter Kauss. This study was designed by Bruce Hawkins, Peter Kauss, John Westwood, Andy Gemza, and Rein Jaagumagi. Technical field assistance was provided by crew chiefs Greg Hobson and Wendy Page, Captain Dave Brandreth of the Ministry of the Environment survey vessel Monitor VI, and students Brian Thorburn and Melissa Krausse. Water and sediment chemistry analysis was performed by the Ontario Ministry of the Environment Laboratory Services Branch in Etobicoke. Zooplankton counts and identification were performed by Beroe consultants, while counts and identification of benthic macroinvertebrates were performed by Bill Morton. The report was compiled and edited by Bruce Kilgour, with contributions from Peter Kauss (water and sediment chemistry), Andy Gemza (water chemistry, phytoplankton and zooplankton from the mid-lake stations) and John Westwood (macroflora). Bruce Kilgour analyzed and interpreted the benthic community data.

## TABLE OF CONTENTS

Summary ..... ii
Acknowledgements ..... viii
List of Tables ..... x
List of Figures ..... x

1.0 BACKGROUND ..... 1
- 1.1 Lake Setting and Characteristics ..... 1
- 1.2 Historical Environmental Information ..... 1
- 1.3 Current Land and Water Uses ..... 4

2.0 STUDY OBJECTIVES ..... 6

3.0 METHODS ..... 7
- 3.1 Preliminary Lake Reconnaissance ..... 7
- 3.2 On-Board Water Quality Measurements ..... 7
- 3.3 Current Metering ..... 7
- 3.4 Water Quality ..... 9
  - 3.4.1 Spatial Variation ..... 9
  - 3.4.2 Temporal Variations ..... 9
- 3.5 Sediment Quality ..... 10
- 3.6 Laboratory Analytical Methods ..... 10
- 3.7 Plankton ..... 11
- 3.8 Macroflora ..... 11
- 3.9 Benthic Macroinvertebrate Community ..... 12

4.0 RESULTS AND DISCUSSION ..... 13
- 4.1 Lake Currents ..... 13
- 4.2 Water Quality ..... 13
  - 4.2.1 Temperature and Dissolved Oxygen Profiles ..... 13
  - 4.2.2 General Water Chemistry ..... 14
  - 4.2.3 Water clarity ..... 14
  - 4.2.4 Nutrient Chemistry ..... 14
  - 4.2.5 Bacteria ..... 21
  - 4.2.6 Taste and Odour Problems ..... 21
  - 4.2.7 Metals ..... 21
  - 4.2.8 Organic Contaminants ..... 21
- 4.3 Sediment Characteristics and Quality ..... 22
  - 4.3.1 Core Sediments from Stations 5 and 15 ..... 22
  - 4.3.2 Spatial Survey of Surficial (Recent) Sediments ..... 22
- 4.4 Plankton ..... 31

4.4.1 Phytoplankton . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 31
4.4.2 Zooplankton . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 31
4.4.3 Zebra Mussel Veliger Larvae . . . . . . . . . . . . . . . . . . . . 34
4.5 Macroflora . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 34
4.6 Benthic Macroinvertebrates . . . . . . . . . . . . . . . . . . . . 46

5. OVERVIEW OF ENVIRONMENTAL QUALITY . . . . . . . . . . . . . . 41

6. RECOMMENDATIONS . . . . . . . . . . . . . . . . . . . . . . . . 43

7. REFERENCES . . . . . . . . . . . . . . . . . . . . . . . . . . . 44

## LIST OF TABLES

Table 1. Water chemistry data representative of the general water quality of Lake Couchiching, 1997. . . . . . . . . . . . . . . . . . . . . 15

## LIST OF FIGURES

Figure 1. General location of Lake Couchiching and its catchment. . . . . . . . . . 2
Figure 2. Map of Lake Couchiching showing points of interest, intakes and discharges, and depth contours (m). . . . . . . . . . 3
Figure 3. Map of Lake Couchiching showing locations of the 21 sampling locations for water, sediments, benthic macroinvertebrates, and aquatic plants. . . . . . . . . . 8
Figure 4. Seasonal variations in Secchi disc depths (m) in 1977 and 1997. . . . . . . . . . 17
Figure 5. Seasonal variations in concentrations of chlorophyll *a* (a), and total phosphorus and TN:TP ratio (b) at Station 5 in Lake Couchiching during 1997. . . . . . . . . . 18
Figure 6. Spatial variations in total phosphorus concentrations in Lake Couchiching on June 3 and July 7/8. . . . . . . . . . 20
Figure 7. Concentrations of chloride, zinc and lead with increasing depth at Stations 5 and 15 in Lake Couchiching. . . . . . . . . . 23
Figure 8. Concentrations of mercury, cadmium and copper with increasing depth at Stations 5 and 15 in Lake Couchiching. . . . . . . . . . 24
Figure 9. Spatial variations in surficial sediment concentrations of chloride, zinc and lead in Lake Couchiching. . . . . . . . . . 27
Figure 10. Spatial variations in surficial sediment concentrations of copper, arsenic and cadmium in Lake Couchiching. . . . . . . . . . 28
Figure 11. Spatial variations in organic carbon, Kjeldahl nitrogen and phosphorus concentrations in surficial sediments. . . . . . . . . . 29

Figure 12. Seasonal trends in algal community composition at Station 5 in Lake Couchiching during 1997. . . . . . . . . . 32
Figure 13. Seasonal zooplankton succession at Station 5 in Lake Couchiching, 1997. . . . . 33
Figure 14. Underwater photo of a benthic algal growth at Station 2 in Lake Couchiching. . . . . . . . . . 36
Figure 15. Map of Lake Couchiching showing the percent composition of major groups of benthic macroinvertebrates at each station in 1997. . . . . . . . . . 38

# Background

## 1.0 BACKGROUND

### 1.1 Lake Setting and Characteristics

Lake Couchiching derives its name from the native peoples, who referred to this lake as "Lake of Many Winds". Lake Couchiching is part of the Trent-Severn Waterway, connecting Lake Ontario with Georgian Bay (Figure 1). Water enters the lake from Lake Simcoe at Atherley Narrows and flows north. Located in Simcoe County (Latitudes 44°36' to 44°45' N; Longitudes 79°20' to 79°25' W), the lake is bordered by the Townships of Orillia, Rama and Mara, which together encompass an area of about 72,000 hectares; of this, 64.44 $km^2$ drains into Lake Couchiching (Cumming Cockburn, 1992). Geologically, the land immediately surrounding Lake Couchiching varies considerably, ranging from a sand plain adjacent to the west and south shores, to a clay plain dotted with drumlins along the lower eastern shore in Mara Township, which is separated by a limestone plain from the Canadian Shield along the upper half of the east shore (Chapman & Putnam, 1966).

Lake surface area and shoreline length are about 44.75 $km^2$ (12,100 acres) and 45 kilometres (28 miles), respectively (Jones & Veal, 1972). One large island (Chiefs Island) and several smaller ones (Horseshoe, Heron and Garnet) comprise a land area of 0.84 $km^2$, with a total shoreline length of 14.6 km.

Lake Couchiching is relatively shallow, with a maximum depth of 12 m (39 feet) and an average, or mean, depth of 6 m (20 feet). The deepest areas are located at: roughly the midpoint of the lake, halfway between Amigo Beach and Quarry Bay; and from just south of Horseshoe Island to near Orillia. Nevertheless, the shallowness of the lake prevents any significant thermal stratification during the summer.

Apart from the Lake Simcoe inflow to the lake at Atherley Narrows (Figure 2), tributaries to Lake Couchiching are relatively small. They include: Sucker Creek, on the east shore near Garnet Island; an unknown creek on the west shore, opposite Chiefs Island; Robinsons Creek at Amigo Beach, with two discharge points; and another unknown creek on the west shore, opposite Green Island. Outflow of Lake Couchiching to Lake Huron is through three channels at its northern end: the Severn River, with two branches; and the Trent Canal.

### 1.2 Historical Environmental Information

Available water quality data for Lake Couchiching is largely out-dated, dating back to the late 1970's. During June of 1972, dissolved oxygen and temperature profiles were determined by the Ministry of Natural Resources (unpublished data). Between late June and late August of 1977, the Ontario Ministry of Environment characterized dissolved oxygen, temperatures and other basic water quality parameters (unpublished data). Between 1971 and the end of 1993, water quality information was obtained through the Ministry of the Environment's Provincial Water Quality Monitoring network at both the inflow and outflow of the lake: samples were collected monthly at both the inlet (Highway 12, at Atherley) and outlet (Highway 169, at Washago) of the lake. In addition, the inflow water quality to the lake has been monitored bi-weekly since 1990, as part of the Lake Simcoe Environmental Management Strategy. Flow rate has been monitored by the Water Survey of Canada at several discharge points of the lake since 1963, but only water level is recorded at the inlet to the

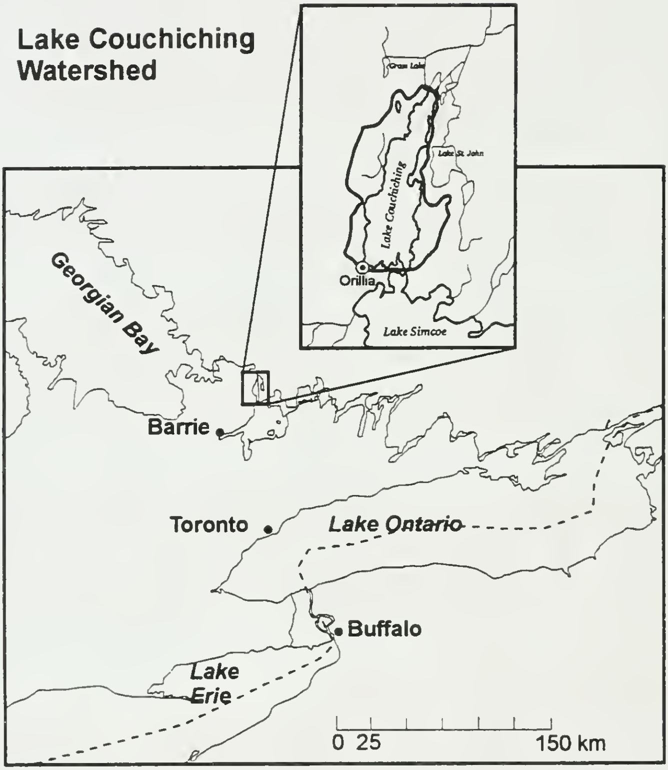

Figure 1. General location of Lake Couchiching and its catchment.

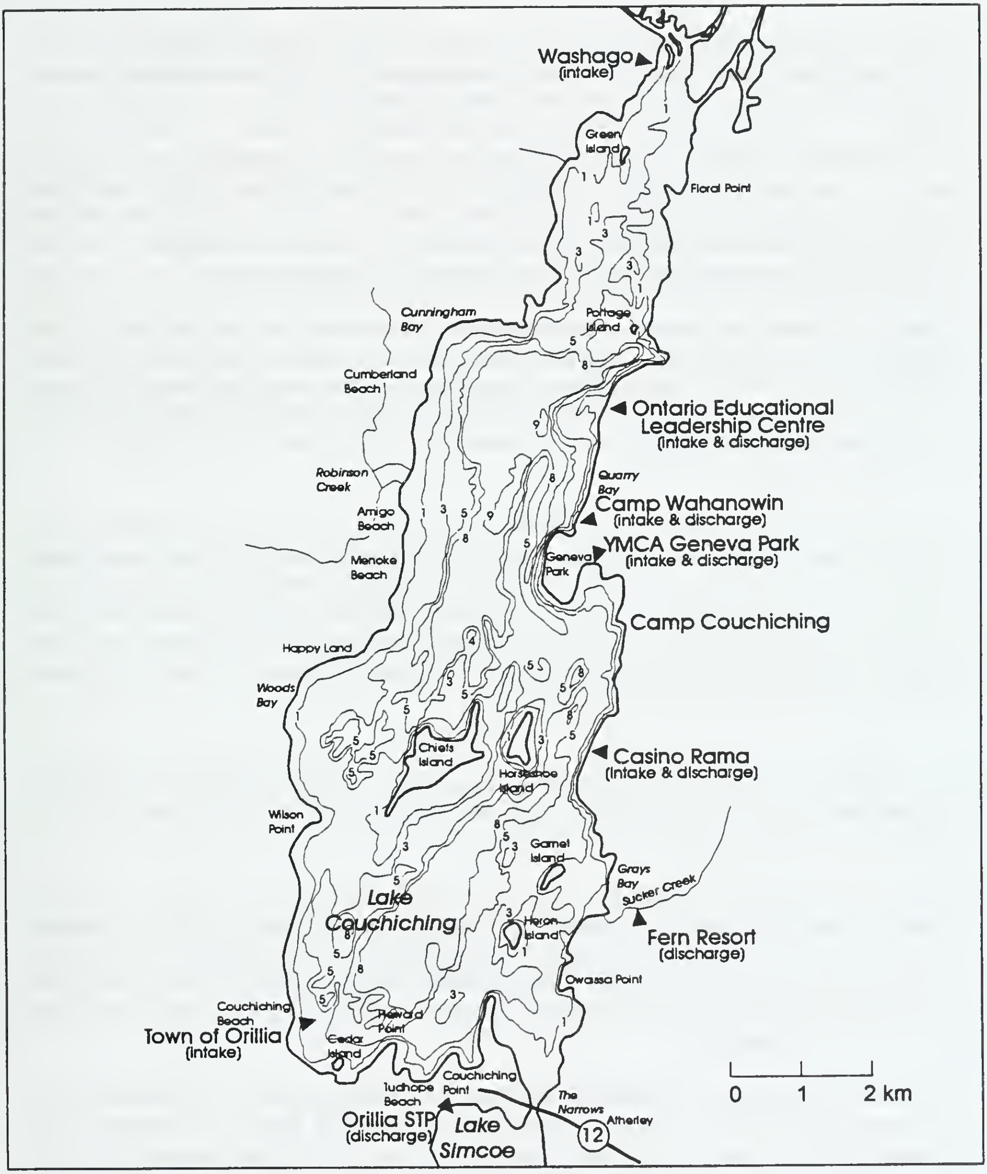

Figure 2. Map of Lake Couchiching showing points of interest, intakes and discharges, and depth contours (m).

lake by Environment Canada. The latter data were used to derive an estimated long-term (1963 to 1990) average Lake Simcoe discharge to Lake Couchiching of 28.63 $m^3/s$, as well as the export of nitrogen and phosphorus from Lake Simcoe (Cumming Cockburn, 1992).

Some biological surveys have been conducted on Lake Couchiching. The earliest study of aquatic plants was conducted at 86 stations by OMOE in July, 1972 (Jones and Veal 1972). This revealed a large standing stock of aquatic macrophytes in the shallow waters (<8 m depth) of the lake, with the major species in decreasing importance being *Chara*, tapegrass (*Vallisnaria americana*), Eurasian Water Milfoil (*Myriophyllum* spp.) and different pondweeds (*Potamogeton* spp.).

Biological monitoring of persistent contaminants was conducted by the Ontario Ministry of the Environment in 1996. Young-of-the-year yellow perch were collected from the lake at three nearshore locations in the lake (upper, middle eastern and bottom). Analysis of PCBs and organochlorine pesticides did not find any concentrations above guidelines for the protection of higher trophic levels (i.e., larger fish or fish-eating birds; G. Hitchin, Ontario Ministry of the Environment, pers. comm., 1998).

Being shallow, Lake Couchiching supports a warm-water fishery. Key recreational species include walleye, largemouth and smallmouth bass, northern pike and yellow perch. Persistent contaminants in sport fish have been monitored over the years by the Ontario Ministry of the Environment. Currently, restricted consumption advisories for humans are in effect for larger sizes of smallmouth bass, largemouth bass, walleye, northern pike and yellow perch due to mercury levels above safe levels (>0.5 mg/kg). PCB concentrations in the dorsal fillets are, however, at safe concentrations set by Health Canada (<0.5 mg/kg, OMOEE, 1997).

### 1.3 Current Land and Water Uses

Land in the Lake Couchiching watershed is used for agriculture. A number of insecticides, fungicides and herbicides are used on the field fruit and vegetable crops. Of the latter, phenoxy acid and triazine herbicides predominate (Hunter and McGee, 1994).

Washago, Orillia, Ontario Educational Leadership Training Centre, YMCA Geneva Park, Camp Wahanowin and Casino Rama have drinking water intakes in the lake (Figure 2). Of the discharges to the lake (Figure 2 and Appendix A), those of Casino Rama include a continuous discharge from a sewage treatment plant as well as effluent from a wetland stormwater treatment facility. Discharges from the Ontario Educational Leadership Training Centre, YMCA Geneva Park, Camp Wahonowin and Fern Resort are seasonal.

Public and private beaches are located all around Lake Couchiching (Figure 2). The Simcoe County Department Health Unit in Midhurst regularly monitors bacterial densities at Washago Park, Couchiching Beach Park, Tudhope Beach, Fern Resort, Camp Couchiching, Geneva Park, Camp Wahonowin and the Ontario Student Leadership Camp. Levels of faecal coliform bacteria (the bacteria associated with health risks) have routinely been low (Katona, 1998).

Urban development is largely concentrated in Orillia, although a number of smaller communities are scattered around the shoreline (Figure 2). Concerns related to water quality impacts have been expressed regarding an increase in development around Lake Couchiching in recent years. Most notable was the construction of the Casino Rama complex and associated developments on the east shore of the lake. This led to requests being received by Southwestern Region of the Ontario Ministry of the Environment from the local municipalities and from the Ministry's District Office in Barrie for a whole-lake environmental characterization.

Residents of Orillia have complained about poor taste and odour of municipal water supplies originating from Lake Couchiching. Taste and odour problems have been attributed to two compounds (geosmin, or 1,10-trans-dimethyl-trans-9-decalol, and 2-MIB or 2-methylisoborneol) that originate primarily in algae. Previous work has shown that algal densities in the water column of Lake Couchiching are below thresholds that would cause taste and odour problems (Katona, 1998). It has been suggested, however, that green and blue-green algae that reside on the bottom of the lake may be responsible for the poor taste and odour.

# Study Objectives

## 2.0 STUDY OBJECTIVES

Based on the extensive recreational use of the lake, the increased level of development along its shores, and poor water quality (for consumption), this study had the following objectives:

(i) to establish a baseline database with respect to the lake's limnology, water, sediment and biological quality,

(ii) to define the existing aquatic environmental quality and trophic status of Lake Couchiching (i.e., at the present level of development); and,

(iii) to develop recommendations concerning possible impacts associated with future development.

Based on these overall objectives, this study characterized water and sediment quality at several locations in Lake Couchiching. This study also characterized bacteria, phytoplankton, zooplankton, macroflora (macroalgae and macrophytes) and benthic macroinvertebrate communities. This study did not attempt to characterize the condition of fish populations in Lake Couchiching since the local Ministry of Natural Resources offices routinely updates that information. Phytoplankton, zooplankton, macroflora, and benthos are however, capable of being used as early warning indicators of potential effects on fish populations in the lake. Surveys were conducted throughout the ice-free period in 1997.

# Methods

## 3.0 METHODS

### 3.1 Preliminary Lake Reconnaissance

On May 6, 1997 a reconnaissance survey was conducted by staff from the Ontario Ministry of the Environment to determine the nature of sediments and the benthic habitat of the lake. In all, 19 locations were sampled, using a Ponar grab. Water depth, grab fullness, sediment characteristics and any flora and fauna present were noted and recorded. This information (Appendix B) was used to select the areas and stations to be sampled later for water quality, sediment quality, benthic communities and aquatic plants.

Based on the results of the reconnaissance survey, 21 stations were selected for sampling. Of these 21 stations, four were situated at roughly mid-lake positions (Stations 5, 12, 15, 21). Stations 5 and 15 were considered to be indicative of whole lake quality. Station locations and map coordinates, are listed in Appendix C and shown in Figure 3. Discrete sampling locations were fixed using an on-board computer equipped with a navigation software package *Hydro*®, interfaced to a Trimble® differential global positioning system (GPS). This permitted an on-board visual display of when the station location had been reached.

### 3.2 On-Board Water Quality Measurements

Prior to the collection of water samples in June and July, spatial variations in chlorophyll, conductivity and temperature were determined by following a pre-determined course around the lake and using on-board metres. A Chelsea Aquatracka Model 3 UV-fluorescence metre was used to determine chlorophyll concentrations and a Hydrolab Datasonde unit for the remaining measurements. Data was stored in an on-board computer interfaced to the Trimble® differential global positioning (GPS) unit and plotted with the navigation software package *Hydro*®.

Concurrent with water quality sampling during the June and July surveys, water temperature, conductivity, pH, and dissolved oxygen were also measured at ~1 metre depth increments, using a pre-calibrated Hydrolab Datasonde unit. Data was stored in an on-board computer interfaced to a Trimble® differential GPS unit.

Depth of visible light penetration was determined with a Secchi disc at each station. Also, Photosynthetically Active Radiation (400-700 nm) was profiled with a LI-COR model LI92SA Underwater Quantum Sensor connected to a LI000 DataLogger. At the three deepest stations (5, 15 and 17), the light extinction coefficient was calculated from a plot of the transmitted light fraction in relation to depth.

### 3.3 Current Metering

Current speed, current direction and water temperature were measured during the water quality survey in early June to provide information on the flow structure within the lake, as well as the velocities nearer the shore (e.g., near some of the beach locations). Locations of these 25 stations (Appendix C) were somewhat different from those used for water and sediment quality sampling. At each station, one or two Mini-Aanderaa Model SD-2000 metres (set to record at the minimum time interval of 8 minutes) were deployed to measure current velocity and direction for 45 minutes. At locations where major flows were anticipated (e.g., between islands), the metres were left in for

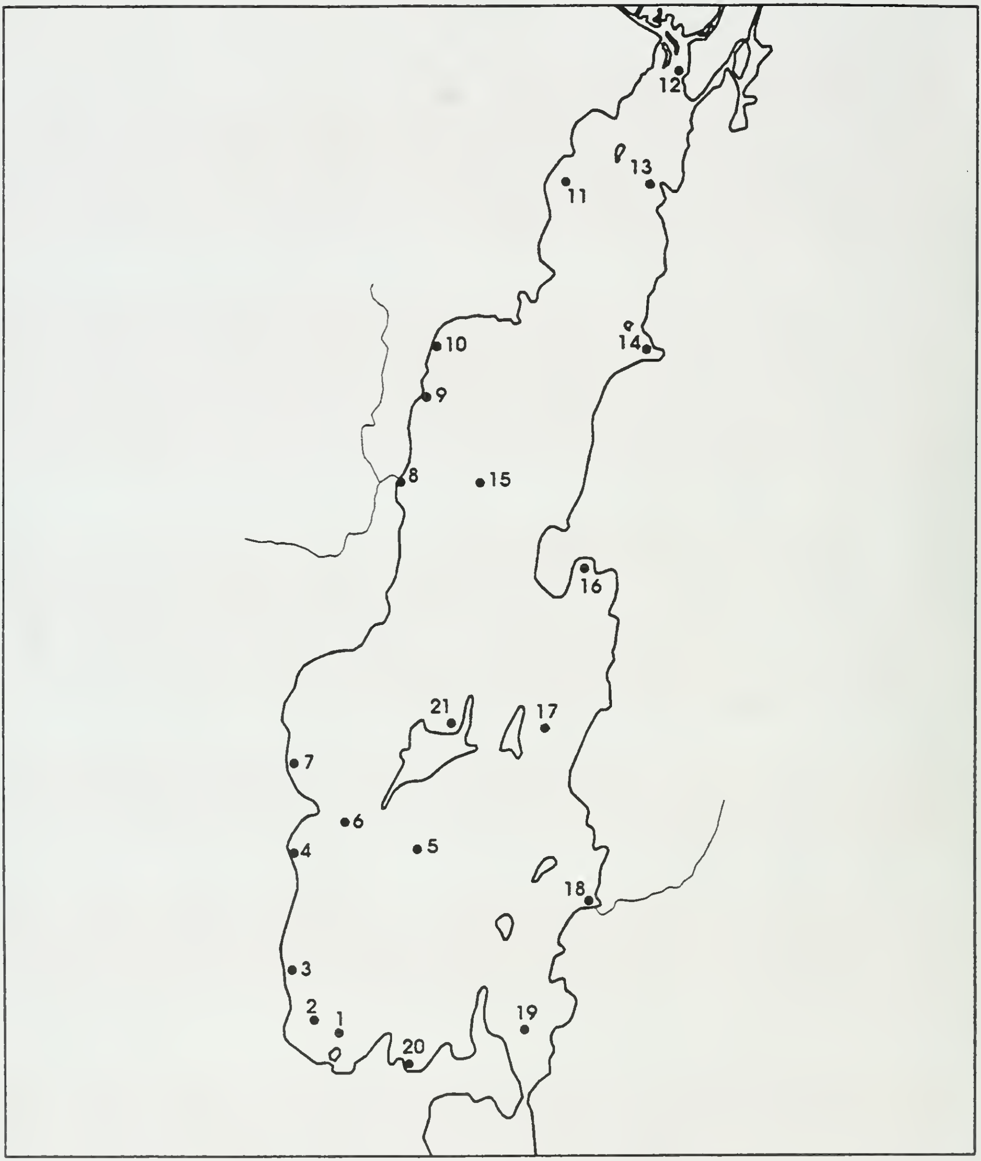

Figure 3. Map of Lake Couchiching showing locations of the 21 sampling locations for water, sediments, benthic macroinvertebrates and aquatic plants.

a longer time period (e.g., several hours or overnight). At each station, the meter(s) were attached to a weighted line with a marker buoy and deployed at 1 metre below surface (or 20 % of the water depth, whichever was greater) and at 1 metre above the bottom (or 80 % of the water depth, whichever was the shallower). At stations of less than 3 m water depth, the current meter was deployed only at mid-depth. The deployment and retrieval times were recorded for each meter and station depth, along with any other pertinent observations. Data recorded by the meters was later downloaded for interpretation.

During the May 28-June 2 surficial sediment quality sampling, current speed was also determined at approximately 0.2 m above bottom at each station, using a Marsh-McBirney meter, while the survey vessel was anchored. Measurement period was at least 30 minutes, with a minimum of three data points being recorded during that period.

## 3.4 Water Quality

### 3.4.1 Spatial Variation

To characterize spatial variation in water quality, water samples were collected at the 21 stations (Stations 1 to 21, Figure 3) in late spring (June 3) and summer (July 7-8). Most of these stations were situated around the periphery of the lake. Stations included potentially impacted (e.g., urban development, with point source discharge) and unimpacted (i.e., undeveloped) areas, and four open-water sites. Analyses carried out on the water samples are provided in Appendix D. Due to analytical capacity limitations, chlorophenols, phenoxy acid herbicides and triazine herbicides could only be analyzed for on samples from the June 3 survey.

On each survey, grab water samples were collected from 1 metre below the surface, using a March Model 5C MD submersible pump and Teflon®-lined hose system that had been cleaned with hexane and distilled water before the beginning of each day's sampling. Once on station, the pumping system was flushed for five minutes with lake water prior to actually taking samples. Except for those bottles that had been pre-cleaned or which already contained a preservative, sample containers were rinsed twice with sample water before filling.

In addition to the routine sample collections, on each survey two additional replicate samples were collected at two stations randomly selected from the total of 21 and submitted for all analyses except bacteria. Data from these samples was used to provide information on sample handling, analytical reproducibility, and short-term temporal variability. To obtain information on potential field and sample container effects, one set of field procedural blank samples was also obtained for each survey by pouring distilled water through the collection system and submitted for all analytical requests except bacteria. To provide data on potential sample container effects, one set of distilled water travel blanks was obtained by filling the required bottles for all analytical requests except bacteria at the laboratory and transporting them to the field and back.

### 3.4.2 Temporal Variations

Of the 21 water quality stations, four located in a line up the centre of the lake (5, 12, 15, 21; Figure 3) were selected for more detailed analysis of trends through time and variations with depth. At these stations, water samples were collected approximately bi-weekly between June 3 and October

23, 1997. These four stations were selected because they were considered to represent general lake quality. To determine whether sediment nutrient release may be taking place, samples from 1 metre off bottom (1 MOB) were also retrieved at the two deeper stations (5 and 15). Euphotic zone samples were collected by lowering and raising a weighted narrow-mouthed (2 cm) glass bottle through the water column. The bottles were lowered through two times the measured Secchi disc depth to a maximum of 1 MOB. Samples from 1 MOB were retrieved by activating a 6-litre, Kemmerer sampler at depth.

Sub-samples for water chemistry were transferred from the collection bottles or sampler to the required sample containers and preserved following OMOE (1989) procedures. Samples were then analyzed for metals, chlorophyll and nutrients (Appendix D). Oxygen and temperature profiles were determined using an air-saturated calibration of a YSI Model 58 combination dissolved oxygen and temperature probe.

### 3.5 Sediment Quality

Between May 29 and June 2, surficial sediment samples were collected at each of the 21 stations (Figure 3). At each station, sufficient surficial sediment (upper 5 cm) was collected using a stainless steel Ponar grab. Between stations, the Ponar was rinsed with hexane and distilled water to eliminate potential cross-contamination. At all but two stations, three replicate surficial sediment samples were obtained, composited and homogenized in a hexane and distilled water rinsed stainless steel tray. At the remaining two randomly-selected stations, the three replicates were processed separately to provide estimates of within-station spatial variability.

On June 4, four replicate core samples were collected from each of the two deeper stations (5 and 15) using a Hobson-Benthos corer and 6.7 cm ID plastic core tubes of about 1 m in length. Each tube and end caps were pre-cleaned with hexane and lake water before use. The cores were brought back to shore, where they were individually sectioned at 0-5 cm (the surface layer), followed thereafter by 10 cm intervals (i.e., 5-15 cm, 15-25 cm, etc.). For each core section, the four replicates were then composited and homogenized as described above for the surficial sediment grabs.

While still on site, a subsample of each sediment composite or replicate was weighed using a small glass jar of known volume. The remaining material was then distributed among the required sample jars/containers and preserved as required (OMOE, 1989). With sediment core sections from stations 5 and 15, all but trace organic contaminants were analyzed for (Appendix E), pending receipt and review of the surficial sediment data. All surficial sediment grab samples were analyzed for nutrients, particle size distribution, oils and greases, total petroleum hydrocarbons, heavy metals, and organic contaminants (Appendix F). Sufficient extra sediment from each surficial sediment or core depth increment was put in an amber (trace organics) jar labelled with the station number, field sample number, and was kept frozen (-20°C) until all laboratory analyses had been received and reviewed.

### 3.6 Laboratory Analytical Methods

Water and sediment samples were submitted to the Ministry laboratories in Etobicoke and analyzed according to documented procedures (OMOEE, 1993; OMOEE 1994a; OMOEE, 1994c-d; OMOEE 1995a-c).

### 3.7 Plankton

At the four mid-lake stations (5, 12, 15, 21), plankton abundance and species composition were monitored approximately bi-weekly, between June 3 and October 23.

*Phytoplankton*

Only Station 5 was sampled bi-weekly to characterize temporal variation. For the three remaining mid-lake stations, bi-weekly algal samples were pooled for an annual "recombined" analysis to assess spatial variation and to provide an inventory of species. Samples were collected by allowing a weighted 1-L bottle with a restricted inlet to fill as it was lowered and raised through the euphotic zone (twice the Secchi disc depth). Samples were immediately fixed with Lugols solution, and transported to the OMOE laboratory on Resources Road. Phytoplankton samples were analyzed according to Gemza (1995a).

*Zooplankton*

Only Station 5 was sampled bi-weekly, to assess temporal changes and to obtain a species inventory. Samples were collected using a metered Clarke-Bumpus style conical net (80-$\mu$m mesh) lowered to 1 m above bottom and then retrieved to the surface at a fixed rate. The sample was rinsed from the net into a 4 oz. glass jar, preserved with 4 % sugared formalin and stored for later analysis as described by Gemza (1995b).

### 3.8 Macroflora

Macroflora were characterized visually at the 21 stations on July 7. On August 6 and 7, grab samples of macroflora were collected at each of these stations. The macroflora sampling in August was conducted with the use of a grapnel employing a modified approach of methods outlined by Schloesser and Manny (1984). The five-hook grapnel was 40cm long and 27cm in diameter. The grapnel was lined with 1cm square wire mesh.

The grapnel was dragged behind the boat at a slow, constant speed so that the grapnel remained on the bottom substrate. Three 10 m long hauls were collected at each sampling station. The abundance of plants on the grapnel was recorded by the collector (subjectively) as: H- heavy (grapnel obscured by plant bio-mass); M-moderate (grapnel wire mesh screen covered with plant bio-mass); P-present (grapnel wire mesh screen less than covered with plant biomass); and, V- void (no plant biomass). The plants were identified in their order of dominance (by volume) on the grapnel. Macrophytes and macroscopic algae were identified following Fassett (1957), Newmaster et al (1997), and Schloesser (1986). A reference collection of plants was made and is retained at the London Regional Office of the Ministry of the Environment.

In addition to these observations made at specific sampling points, a depth sounder (Lowrance X16 sonar unit with paper graph recording) was used to characterize distributions of macroflora with depth along three transects (Appendix C):

1)-From Cunningham Bay on the west shore to the north tip of Geneva Park on the east shore.
2)-From Maniac Beach (south) on the west shore to south of Geneva Park on the east shore.
3)-From the Nathan area on the west shore to Garnet Island near the east shore.

The transects were started at the 1-m depth contour on the west shore and were continuous to their termination on the east shore.

### 3.9 Benthic Macroinvertebrate Community

Benthic fauna associated with surficial sediments were also collected during the May 29-June 2 surficial sediment quality survey at each of the 21 sediment sampling stations (Figure 3). Three replicate samples were obtained by stainless steel Ponar grab at each station and individually sieved through a 600-$\mu$m mesh Nitex bag using clean lake water. Organisms and detritus retained in the bag were preserved with buffered formalin in wide-mouth plastic jars with a screw cap. For each grab, the percentage fullness of the Ponar grab, the percentage macrophyte cover and species present, the sediment characteristics and any obvious fauna were recorded on the field note sheets (Appendix K).

At each station, a fourth replicate Ponar grab was collected and placed directly in a covered plastic pail. These samples were picked up by staff of the Ministry's Aquatic Sciences Section in Dorset for processing (picked live) according to the Rapid Bioassessment protocol (David *et al.* 1998). These data have been reported separately (David *et al.*, 1998).

*Analysis and Interpretation*

Analysis and interpretation of the benthic community in Lake Couchiching had two general objectives:

- to establish trophic condition of the lake; and,
- to determine the degree to which local point sources, and natural features and anthropogenic features influence benthic community composition.

Known tolerances of benthic organisms were used to establish the trophic status of the lake. In addition, detailed statistical procedures were used to establish the associations between benthic community composition and local point sources and variations in habitat quality. The details of the various statistical and interpretational methods are given in Appendix J.

# Results and Discussion

## 4.0 RESULTS AND DISCUSSION

This section reviews the general findings of the various sampling programs. The objective of this discussion is to highlight those findings that directly impact this characterization of environmental quality. In some cases, the data obtained led to very obvious conclusions and did not require excessive summary. For example, persistent chlorinated organic contaminants were not found in any sediment samples. Trends were therefore obvious, so no data summaries are provided in the main body of the report (Volume I). Most of the raw data collected in this study, however, is provided either in the main document, or in the appendices (Volume II). For conciseness, an attempt was also made to summarize the results of complimentary surveys. For example, temporal variations in water quality were characterized by collecting water samples at mid-lake stations every two weeks, while spatial variations in water quality were characterized by collecting water samples at stations located around the periphery of the lake in June and July. Data over time from the mid-lake stations could be used on their own to classify the lake trophically. Those temporal data are, however, discussed in association with the spatial surveys conducted in June and July at all stations to make a more concise and compelling discussion of lake trophic status. This section deals first with chemical and physical aspects of the lake, then biological aspects.

### 4.1 Lake Currents

Current velocities and directions were determined at the 21 stations during the late May-early June survey, but in more detailed fashion between June 4 and 6 at 24 "current" stations (Appendix C). This discussion focuses on the data from the 24 current stations. Current data are provided in Appendix D. In general, water currents in the lake were slow, averaging from 0.3 to 11.2 cm/s. Of these, the fastest currents were recorded at stations just off Couchiching Point (5.4 cm/s, near the bottom), off Wilson Point (5.9 cm/s), just north of Mariposa Beach (9.4 and 5.2 cm/s) and at Cedar Island (11.2 cm/s). Greatest short-term variability of current speed was usually observed at the deepest stations, located offshore and along the north-south axis of the lake, and off Woods Bay. Near Atherley Narrows, current speed was somewhat higher just off the bottom than just below the surface. Surface waters typically flowed west-northwest or north-northeast, but surface and bottom waters did not always flow in the same direction.

### 4.2 Water Quality

Variations in key water quality characteristics that are important to algae, zooplankton, benthos and fish are summarized below. Raw water quality data are presented in Appendix D.

#### 4.2.1 Temperature and Dissolved Oxygen Profiles

By May 27, there was spatial variation in surface temperatures (8 to 14 °C) with higher temperatures along the western half of the lake, particularly the nearshore area north of Orillia. By June 3 surface water temperatures averaged 16 °C and by July 8 averaged 21 °C. Mid-lake temperatures peaked on July 22 at 22 °C, falling to 10 °C on October 23 (Appendix D).

Because Lake Couchiching is relatively shallow for its size, the water column is usually fully mixed. Temperatures are, therefore, generally isothermal and dissolved oxygen concentrations remain high even near the bottom in deeper areas of the lake. Evidence for slight thermal stratification was evident at the deepest station (5) in early and mid June (Table 1). Oxygen concentrations were as low as 6.2 mg/L in June, but ranged between 8.0 and 10.5 mg/L through the remainder of the summer (Table 1).

### 4.2.2 General Water Chemistry

Lake Couchiching is a basic, hardwater lake. At the four open water stations (5, 12, 15, 21), pH ranged between 8.2 and 8.4, while mean annual alkalinity levels ranged between 102 and 111 mg/L. Mean annual calcium concentrations ranged between 37 mg/L at station 12, to 41 mg/L at station 5. Alkalinity and calcium levels were marginally higher in the spring. At the mid-lake stations, conductivity was about 330 $\mu$S/cm (Table 1). Given the local geology, the lake is at no risk of effects from acidic precipitation.

### 4.2.3 Water clarity

Lake Couchiching had good water clarity; Secchi discs were still visible on the bottom of the lake at all of the shallow-water (2-3 m deep) stations. At the mid-lake stations, Secchi disc depth ranged between 4.0 and 7.0 m, with an annual mean of 5.1 m (Figure 4, Table 1). Peak Secchi depths representing the clear water phase were measured on June 17. Visibility declined through late August to the end of September with readings as low as 4.0 m. Based on these figures for Secchi disc depths, Lake Couchiching can be classified as either oligotrophic or mesotrophic. Vollenweider (1972; as cited in Wetzel, 1983) showed that lakes considered mesotrophic have an average Secchi disc depth of about 4.2 m but can range between 1.5 and 8.1 m. According to Carlton(1977), lakes with a Secchi dis depth greater than 5 m are oligotrophic, while those with Secchi disc depths between 2 and 5 m are mesotrophic. Water clarity in Lake Couchiching is also obviously adequate for swimming. Health and Welfare Canada (1983) suggests that Secchi disc depths should exceed 1.2 m to ensure that subsurface hazards can be observed.

Clarity in Lake Couchiching increased substantially between 1977 and 1997 (Figure 4). Based on the assumption that nutrient levels in the lake have not decreased since 1977, increased clarity in Lake Couchiching is probably associated with the presence of zebra mussels in the lake. Zebra mussels feed by filtering algae and bacteria from the water column (Stoeckmann and Garton 1997). In shallow lakes (like Lake Couchiching) it has been estimated that zebra mussel populations can filter the equivalent volume of a lake between 0.2 and 1.3 times daily (Fanslow et al. 1995).

### 4.2.4 Nutrient Chemistry

Several nutrients are important in determining the productive potential of algae, zooplankton, benthos and fish. In the discussion below, we focus on total phosphorus because the lake is phosphorus limited, and because lake trophic classification can be based on total phosphorus concentrations. Variations in chlorophyll *a* concentrations and silica were also summarized because they are both related to variations in phytoplankton abundances.

*Total Phosphorus*

In both the open lake and nearshore areas, the ratio of total nitrogen to total phosphorus (TN:TP) varied between 30 and 60 depending on the time of year (Figure 5, Table 1). Ratios in excess of 20:1 generally imply that phosphorus limits the production (growth) of algae (Wetzel, 1983; Smith, 1986). Phosphorus is therefore limiting in Lake Couchiching.

Table 1. Water chemistry data representative of the general water quality of Lake Couchiching, 1997.

| STATION 5 | June 3 | | June 17 | | July 8 | | July 22 | | August 8 | | August 22 | | September 10 | | September 25 | | October 7 | | October 23 | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Euphotic Zone | | | | | | | | | | | | | | | | | | | | | |
| Secchi disc depth (m) | 5.5 | | 7.0 | | 5.5 | | 6.1 | | 4.5 | | 4.0 | | 4.0 | | 4.0 | | 6.3 | | 4.5 | | 5.1 |
| Chloride | 26.6 | | 26.8 | | | | 27.0 | | 27.6 | | 27.4 | | 27.6 | | 27.4 | | 28.0 | | 28.0 | | 27.4 |
| Chlorophyll a | | | 1.0 | | | | 2.6 | | 1.2 | | 0.4 | | 0.8 | | 0.6 | | 1.0 | | 1.0 | | 1.1 |
| Calcium | | | 43.30 | | | | 40.60 | | 40.60 | | 40.00 | | 39.60 | | 40.20 | | 40.20 | | 41.00 | | 40.69 |
| Magnesium | | | 6.880 | | | | 7.080 | | 7.160 | | 7.160 | | 7.240 | | 7.320 | | 7.140 | | 7.320 | | 7.163 |
| Sodium | | | 15.80 | | | | 15.70 | | 16.40 | | 15.60 | | 16.20 | | 16.40 | | 15.30 | | 16.20 | | 15.95 |
| Potassium | | | 1.86 | | | | 1.90 | | 1.84 | | 1.82 | | 1.86 | | 1.84 | | 1.90 | | 2.02 | | 1.88 |
| Sulphate | | | 19.0 | | | | 18.5 | | 18.5 | | 18.5 | | 19.0 | | 18.5 | | 19.0 | | 19.5 | | 18.8 |
| Colour (TCU) | | | 4.2 | | | | 10.4 | | 4.2 | | 4.2 | | 4.0 | | 2.2 | | 4.6 | | 4.6 | | 4.8 |
| Conductivity (µS/cm) | | | 343 | | | | 337 | | 335 | | 322 | | 330 | | 333 | | 336 | | 342 | | 335 |
| pH | | | 8.3 | | | | 8.3 | | 8.4 | | 8.4 | | 8.3 | | 8.3 | | 8.2 | | 8.3 | | 8.3 |
| Alkalinity | | | 117 | | | | 113 | | 110 | | 109 | | 106 | | 110 | | 110 | | 114 | | 111 |
| Turbidity (FTU) | | | 0.82 | | | | 0.90 | | 1.10 | | 1.23 | | 1.19 | | 1.48 | | 1.25 | | 1.67 | | 1.21 |
| Nitrogen: ammonium | 0.008 | | 0.020 | | | | 0.014 | | 0.032 | | 0.028 | | 0.034 | | 0.046 | | 0.038 | | 0.034 | | 0.028 |
| Nitrogen: nitrite | 0.001 | | 0.001 | | | | 0.002 | | 0.002 | | 0.001 | | 0.004 | | 0.002 | | 0.001 | | 0.001 | | 0.002 |
| Nitrogen: nitrate+nitrite | 0.010 | | 0.005 | | | | 0.030 | | 0.010 | | 0.005 | | 0.015 | | 0.025 | | 0.020 | | 0.025 | | 0.016 |
| Phosphorus: phosphate | 0.001 | | 0.001 | | | | 0.003 | | 0.004 | | 0.001 | | 0.002 | | 0.004 | | 0.001 | | 0.001 | | 0.002 |
| Phosphorus: total | 0.008 | | 0.012 | | | | 0.008 | | 0.010 | | 0.010 | | 0.008 | | 0.008 | | 0.008 | | 0.008 | | 0.009 |
| Nitorgen: total Kjeldahl | 0.400 | | 0.340 | | | | 0.480 | | 0.400 | | 0.420 | | 0.460 | | 0.420 | | 0.440 | | 0.420 | | 0.420 |
| TN:TP (ratio) | 51.3 | | 28.8 | | | | 63.8 | | 41.0 | | 42.5 | | 59.4 | | 55.6 | | 57.5 | | 55.6 | | 50.6 |
| Carbon: dissolved organic | 3.7 | | 4.1 | | | | 4.2 | | 4.3 | | 4.2 | | 4.2 | | 4.1 | | 4.2 | | 4.2 | | 4.1 |
| Carbon: dissolved inorganic | 26.6 | | 27.0 | | | | 25.8 | | 25.6 | | 24.6 | | 25.2 | | 25.0 | | 24.6 | | 25.4 | | 25.5 |
| Silicon: reactive silicate | 0.76 | | 0.88 | | | | 1.58 | | 1.66 | | 1.44 | | 1.36 | | 1.36 | | 1.30 | | 1.32 | | 1.30 |
| Aluminium | 0.005 | | 0.007 | | 0.008 | | 0.006 | | 0.006 | | 0.009 | | 0.006 | | 0.008 | | 0.007 | | 0.007 | | 0.007 |
| Iron | 0.009 | | 0.008 | | 0.003 | | 0.004 | | 0.005 | | 0.006 | | 0.004 | | 0.009 | | 0.006 | | 0.007 | | 0.006 |
| Lead | | | 0.002 | | | | 0.003 | | 0.002 | | 0.004 | | 0.007 | | 0.006 | | 0.005 | | 0.001 | | 0.004 |
| 1 MOB | | | | | | | | | | | | | | | | | | | | | |
| Turbidity (FTU) | | | 1.70 | | | | 1.03 | | 1.75 | | 1.44 | | 1.34 | | 1.63 | | 2.10 | | 1.60 | | 1.57 |
| Nitrogen: Ammonium | 0.002 | | 0.016 | | | | 0.022 | | 0.034 | | 0.044 | | 0.048 | | 0.048 | | 0.040 | | 0.036 | | 0.032 |
| Nitrogen: Nitrite | 0.001 | | 0.002 | | | | 0.001 | | 0.005 | | 0.001 | | 0.004 | | 0.002 | | 0.001 | | 0.002 | | 0.002 |
| Nitrogen: nitrate+nitrite | 0.005 | | 0.035 | | | | 0.030 | | 0.015 | | 0.005 | | 0.020 | | 0.025 | | 0.025 | | 0.020 | | 0.020 |
| Total Kjeldahl | 0.440 | | 0.440 | | | | 0.480 | | 0.460 | | 0.480 | | 0.560 | | 0.460 | | 0.440 | | 0.440 | | 0.467 |
| Phosphorus: phosphate | 0.001 | | 0.004 | | | | 0.003 | | 0.003 | | 0.001 | | 0.001 | | 0.003 | | 0.001 | | 0.001 | | 0.002 |
| Phosphorus: Total | 0.008 | | 0.014 | | | | 0.014 | | 0.008 | | 0.008 | | 0.010 | | 0.012 | | 0.008 | | 0.010 | | 0.010 |
| TN:TP (ratio) | 55.6 | | 33.9 | | | | 36.4 | | 59.4 | | 60.6 | | 58.0 | | 40.4 | | 58.1 | | 46.0 | | 49.8 |
| Carbon: dissolved organic | 3.8 | | | | | | | | | | | | | | | | | | | | 3.8 |
| Carbon: dissolved inorganic | 26.6 | | | | | | | | | | | | | | | | | | | | 26.6 |
| Silicon: reactive silicate | 0.72 | | | | | | | | | | | | | | | | | | | | 0.72 |
| Aluminium | 0.005 | | 0.011 | | 0.008 | | 0.009 | | 0.006 | | 0.008 | | 0.007 | | 0.009 | | 0.010 | | 0.007 | | 0.008 |
| Iron | 0.010 | | 0.008 | | 0.004 | | 0.005 | | 0.007 | | 0.006 | | 0.006 | | 0.007 | | 0.010 | | 0.006 | | 0.007 |
| Lead | | | ND | | | | 0.022 | | 0.009 | | 0.012 | | 0.007 | | 0.006 | | 0.023 | | 0.015 | | 0.012 |
| Depth (m) | Oxy. | Temp. | Oxy. | Temp. | Oxy. | Temp. | Oxy. | Temp. | Oxy. | Temp. | Oxy. | Temp. | Oxy. | Temp. | Oxy. | Temp. | Oxy. | Temp. | Oxy. | Temp. | |
| 0 | 7.7 | 14.7 | 9.5 | 19.6 | 8.3 | 20.6 | 8.7 | 22.0 | 9.0 | 21.8 | 8.2 | 19.6 | 9.0 | 18.5 | 10.0 | 15.1 | 10.2 | 15.4 | 9.9 | 9.9 | |
| 2 | 7.0 | 14.6 | 9.4 | 19.6 | 8.3 | 20.6 | 8.4 | 22.0 | 9.5 | 21.8 | 8.2 | 19.6 | 9.0 | 18.5 | 9.8 | 15.1 | 10.4 | 15.0 | 9.9 | 9.9 | |
| 4 | 6.5 | 14.5 | 9.4 | 19.5 | 8.3 | 20.6 | 8.8 | 22.0 | 10.0 | 21.8 | 8.2 | 19.6 | 9.0 | 18.5 | 9.8 | 15.1 | 10.4 | 14.9 | 9.9 | 9.9 | |
| 6 | 6.2 | 14.4 | 9.8 | 19.0 | 8.3 | 20.6 | 8.9 | 21.9 | 10.5 | 21.8 | 8.2 | 19.6 | 8.9 | 18.5 | 9.8 | 15.1 | 10.4 | 14.1 | 9.9 | 9.9 | |
| 8 | 6.3 | 12.3 | 9.8 | 16.1 | 8.2 | 20.6 | 9.0 | 20.1 | 10.5 | 21.8 | 8.2 | 19.6 | 8.8 | 18.5 | 9.8 | 15.1 | 10.2 | 14.1 | 9.9 | 9.9 | |

Legend

Note: All measurements in mg/L unless otherwise indicated.

TN: Total Nitrogen = Nitrates + Nitrites + Kjeldahl

TP: Total Phosphorus

Euphotic Zone: 2x secchi depth

Oxy.: Oxygen (mg/L)

1 MOB = 1 metre off bottom

ND: non-detect

Temp.: Temperature (°C)

Table 1 (cont'd). Water quality of Stations 12, 15 and 21. Lake Couchiching, 1997.

| STATION 12 Euphotic Zone | June 3 | June 17 | July 8 | July 22 | August 8 | August 22 | September 10 | September 25 | October 7 | October 23 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Chloride | 26.8 | 27.2 |  | 27.2 | 27.8 | 27.6 | 28.0 | 27.6 | 27.6 | 28.0 | 27.5 |
| Chlorophyll a |  | 0.6 |  | 1.6 | 0.6 | 0.4 | 0.8 | 0.6 | 0.8 | 0.4 | 0.7 |
| Calcium |  |  |  |  | 36.20 |  | 37.50 |  |  |  | 36.85 |
| Magnesium |  |  |  |  | 7.200 |  | 7.300 |  |  |  | 7.250 |
| Sodium |  |  |  |  | 16.90 |  | 16.20 |  |  |  | 16.55 |
| Potassium |  |  |  |  | 1.95 |  | 1.92 |  |  |  | 1.94 |
| Sulphate |  |  |  |  | 18.0 |  | 19.0 |  |  |  | 18.5 |
| Colour (TCU) |  |  |  |  | 5.0 |  | 3.8 |  |  |  | 4.4 |
| Conductivity (µS/cm) |  |  |  |  | 320 |  | 324 |  |  |  | 322 |
| pH |  |  |  |  | 8.4 |  | 8.2 |  |  |  | 8.3 |
| Alkalinity |  |  |  |  | 101 |  | 102 |  |  |  | 102 |
| Turbidity (FTU) |  | 1.08 |  | 1.67 | 4.10 | 2.10 | 1.55 | 2.70 | 2.50 | 1.48 | 2.15 |
| Nitrogen: ammonium | 0.010 | 0.018 |  | 0.016 | 0.032 | 0.016 | 0.024 | 0.034 | 0.032 | 0.032 | 0.024 |
| Nitrogen: nitrite | 0.001 | 0.001 |  | 0.001 | 0.002 | 0.001 | 0.003 | 0.001 | 0.002 | 0.002 | 0.002 |
| Nirogen: nitrate+nitrite | 0.005 | 0.005 |  | 0.025 | 0.005 | 0.005 | 0.020 | 0.020 | 0.015 | 0.020 | 0.013 |
| Nitrogen: total Kjeldahl | 0.360 | 0.360 |  | 0.480 | 0.500 | 0.420 | 0.460 | 0.440 | 0.340 | 0.440 | 0.422 |
| Phosphorus: phosphate | 0.001 | 0.001 |  | 0.003 | 0.003 | 0.001 | 0.001 | 0.003 | 0.001 | 0.001 | 0.001 |
| Phosphorus, total | 0.006 | 0.006 |  | 0.008 | 0.014 | 0.010 | 0.006 | 0.006 | 0.006 | 0.006 | 0.008 |
| TN:TP (ratio) | 60.8 | 60.8 |  | 63.1 | 36.1 | 42.5 | 80.0 | 76.7 | 59.2 | 76.7 | 61.8 |
| Carbon: dissolved organic | 3.9 |  |  |  | 4.6 |  | 4.3 |  |  |  | 4.3 |
| Carbon: dissolved inorganic | 25.2 |  |  |  | 22.8 |  | 24.0 |  |  |  | 24.0 |
| Silicon: reactive silicate | 0.44 |  |  |  | 1.74 |  | 1.50 |  |  |  | 1.23 |
| Aluminium | 0.006 |  |  |  |  |  |  |  |  |  | 0.006 |
| Iron | 0.007 |  |  |  |  |  |  |  |  |  | 0.007 |
| Lead |  |  |  |  |  |  |  |  |  |  |  |
| STATION 15 |  |  |  |  |  |  |  |  |  |  |  |
| Euphotic Zone |  |  |  |  |  |  |  |  |  |  |  |
| Chloride | 26.8 | 27.0 | 26.8 | 27.2 | 27.4 | 27.6 | 27.8 | 27.6 | 28.0 | 27.8 | 27.4 |
| Chlorophyll a |  | 1.0 | 1.6 | 2.6 | 1.6 | 0.6 | 1.0 | 0.8 | 1.4 | 0.8 | 1.3 |
| Calcium |  |  | 40.30 |  | 39.90 |  | 38.50 |  |  |  | 39.57 |
| Magnesium |  |  | 6.960 |  | 7.120 |  | 7.240 |  |  |  | 7.107 |
| Sodium |  |  | 15.90 |  | 16.50 |  | 16.10 |  |  |  | 16.17 |
| Potassium |  |  | 1.94 |  | 1.86 |  | 1.88 |  |  |  | 1.89 |
| Sulphate |  |  | 16.5 |  | 18.0 |  | 19.0 |  |  |  | 17.8 |
| Colour (TCU) |  |  | 3.8 |  | 4.6 |  | 3.8 |  |  |  | 4.1 |
| Conductivity (µS/cm) |  |  | 335 |  | 333 |  | 326 |  |  |  | 331 |
| pH |  |  | 8.3 |  | 8.4 |  | 8.2 |  |  |  | 8.3 |
| Alkalinity |  |  |  |  | 111 |  | 104 |  |  |  | 108 |
| Turbidity (FTU) |  | 0.88 |  | 1.01 | 0.96 | 2.30 | 1.46 | 1.84 | 1.35 | 1.24 | 1.38 |
| Nitrogen: Ammonium | 0.008 | 0.012 |  | 0.010 | 0.032 | 0.010 | 0.032 | 0.038 | 0.030 | 0.038 | 0.023 |
| Nitrogen: Nitrite | 0.001 | 0.001 |  | 0.001 | 0.002 | 0.001 | 0.003 | 0.002 | 0.001 | 0.002 | 0.002 |
| Nitrogen: nitrate+nitrite | 0.005 | 0.005 |  | 0.025 | 0.005 | 0.005 | 0.025 | 0.020 | 0.025 | 0.025 | 0.016 |
| Nitrogen: total Kjeldahl | 0.360 | 0.360 |  | 0.440 | 0.420 | 0.420 | 0.440 | 0.420 | 0.440 | 0.440 | 0.416 |
| Phosphorus: phosphate | 0.001 | 0.001 |  | 0.003 | 0.003 | 0.004 | 0.001 | 0.002 | 0.001 | 0.001 | 0.002 |
| Phosphorus: total | 0.006 | 0.008 |  | 0.010 | 0.006 | 0.010 | 0.008 | 0.014 | 0.008 | 0.006 | 0.008 |
| TN:TP (ratio) | 60.8 | 45.6 |  | 46.5 | 70.8 | 42.5 | 58.1 | 31.4 | 58.1 | 77.5 | 54.6 |
| Carbon: dissolved organic | 3.8 |  |  |  | 4.3 |  | 4.2 |  |  |  | 4.1 |
| Carbon: dissolved inorganic | 25.8 |  |  |  | 24.8 |  | 24.4 |  |  |  | 25.0 |
| Silicon: reactive silicate | 0.50 |  |  |  | 1.54 |  | 1.40 |  |  |  | 1.15 |
| Aluminium | 0.006 |  |  |  |  |  |  |  |  |  | 0.006 |
| Iron | 0.002 |  |  |  |  |  |  |  |  |  | 0.002 |
| Lead |  |  |  |  |  |  |  |  |  |  |  |
| STATION 21 |  |  |  |  |  |  |  |  |  |  |  |
| Euphotic Zone |  |  |  |  |  |  |  |  |  |  |  |
| Chloride |  | 26.8 | 26.6 | 27.2 | 28.0 | 27.6 | 27.8 | 27.8 | 27.6 | 27.8 | 27.5 |
| Chlorophyll a |  | 0.6 | 0.8 | 1.6 | 1.0 | 0.6 | 1.0 | 0.6 | 0.8 | 0.6 | 0.8 |
| Calcium |  |  | 40.60 |  | 36.70 |  | 38.60 |  |  |  | 38.63 |
| Magnesium |  |  | 6.960 |  | 7.240 |  | 7.260 |  |  |  | 7.153 |
| Sodium |  |  | 17.30 |  | 16.70 |  | 16.20 |  |  |  | 16.73 |
| Potassium |  |  | 1.86 |  | 1.85 |  | 1.89 |  |  |  | 1.87 |
| Sulphate |  |  | 16.0 |  | 18.5 |  | 19.0 |  |  |  | 17.8 |
| Colour (TCU) |  |  | 3.8 |  | 4.8 |  | 3.8 |  |  |  | 4.1 |
| Conductivity (µS/cm) |  |  | 335 |  | 330 |  | 327 |  |  |  | 331 |
| pH |  |  | 8.3 |  | 8.4 |  | 8.2 |  |  |  | 8.3 |
| Alkalinity |  |  |  |  | 107 |  | 105 |  |  |  | 106 |
| Turbidity (FTU) |  | 0.66 |  | 0.86 | 0.75 | 0.90 | 1.49 | 1.39 | 1.10 | 1.21 | 1.05 |
| Nitrogen: ammonium |  | 0.018 |  | 0.016 | 0.032 | 0.024 | 0.026 | 0.038 | 0.030 | 0.032 | 0.027 |
| Nitrogen: nitrite |  | 0.001 |  | 0.001 | 0.006 | 0.001 | 0.004 | 0.002 | 0.001 | 0.002 | 0.002 |
| Nitrogen: nitrate+nitrite |  | 0.005 |  | 0.025 | 0.010 | 0.005 | 0.015 | 0.020 | 0.020 | 0.020 | 0.015 |
| Nitrogen: total Kjeldahl |  | 0.340 |  | 0.460 | 0.480 | 0.400 | 0.460 | 0.420 | 0.480 | 0.420 | 0.433 |
| Phosphorus: phosphate |  | 0.001 |  | 0.003 | 0.002 | 0.001 | 0.001 | 0.002 | 0.001 | 0.001 | 0.001 |
| Phosphorus: total |  | 0.008 |  | 0.008 | 0.006 | 0.006 | 0.008 | 0.008 | 0.008 | 0.006 | 0.007 |
| TN:TP (ratio) |  | 43.1 |  | 60.6 | 81.7 | 67.5 | 59.4 | 55.0 | 62.5 | 73.3 | 62.9 |
| Carbon: dissolved organic |  |  |  |  | 4.4 |  | 4.2 |  |  |  | 4.3 |
| Carbon: dissolved inorganic |  |  |  |  | 24.8 |  | 24.2 |  |  |  | 24.5 |
| Silicon: reactive silicate |  |  |  |  | 1.56 |  | 1.38 |  |  |  | 1.47 |
| Aluminium |  |  |  |  |  |  |  |  |  |  |  |
| Iron |  |  |  |  |  |  |  |  |  |  |  |
| Lead |  |  |  |  |  |  |  |  |  |  |  |

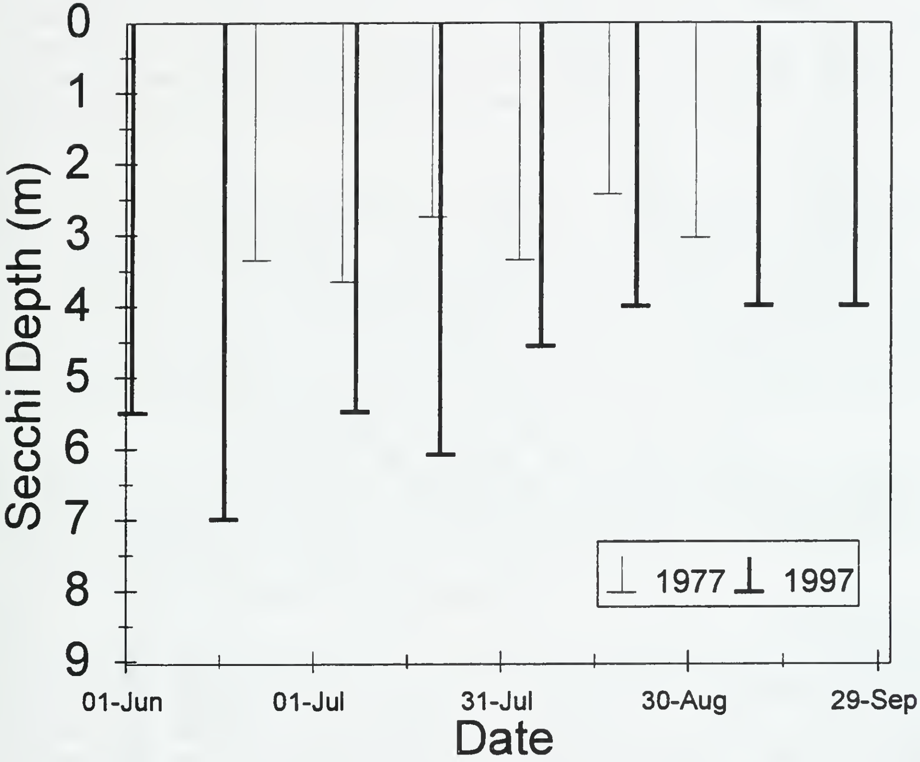

Figure 4. Seasonal variations in Secchi disc depths (m) in 1977 and 1997.

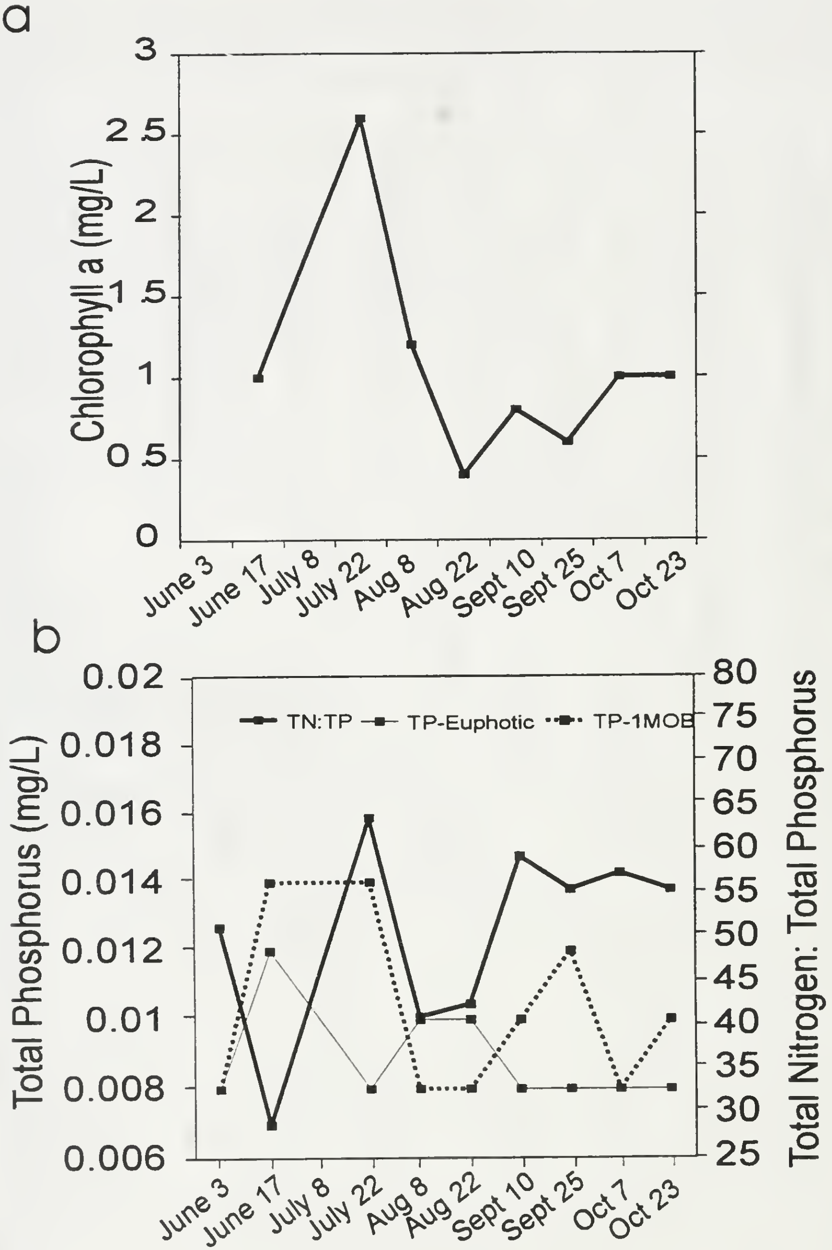

Figure 5. Seasonal variations in concentrations of chlorophyll *a* (a), and total phosphorus and TN:TP ratio (b) at Station 5 in Lake Couchiching during 1997.

Where phosphorus is limiting, the OMOEE (1994b) recommends that total phosphorus concentrations be kept below 0.020 mg/L to avoid nuisance growths of algae. The Ministry also recommends that total phosphorus be kept below 0.010 mg/L to provide a high level of protection against aesthetic degradation. Among the nearshore stations, total phosphorus concentrations ranged between 0.006 and 0.016 mg/L (Figure 6, Appendix D), with concentrations in excess of 0.010 mg/L at all stations during at least one survey with the exception of Stations 11, 19 and 20 (Appendix D). There were no spatial patterns in total phosphorus concentrations that indicated important point sources of pollution.

Phosphorus concentrations at the four mid-lake stations were similar to concentrations at the nearshore stations. Mid-lake annual average total phosphorus concentrations (TP) ranged from 0.007 to 0.009 mg/L (Figure 5, Table 1). Spring concentrations were slightly higher at Station 5, trending downwards as the season progressed. A short-lived TP peak of 0.012 mg/L was detected on June 17 (Figure 5). Total phosphorus concentrations were slightly higher near the bottom with an annual average of 0.010 mg/L and a mid-summer maximum of 0.014 mg/L at Station 12 (Table 1). Variations in euphotic zone and 1 MOB phosphorus concentrations were probably associated with bioturbation (Redshaw et al., 1990), temperatures variations and resuspension of sediments through wind action (Quigley and Robbins, 1986).

The high pH of waters and the presence of carbonate deposits on *Chara* and in the sediments suggest that Lake Couchiching has at least some of the characteristics of a marl lake. In such lakes, primary production is phosphorus-limited, partly because phosphorus is precipitated out of the water column into the sediments, as iron and manganese complexes (Wetzel, 1983).

*Silica*

Silica concentrations varied between 0.34 and 1.56 mg/L among the nearshore stations (Appendix D). Among the four mid-lake stations (5, 12, 15, 21), silica concentrations were lowest in spring, rising through the early summer to peak levels in late July (1.66 mg/L). Levels fell through August before stabilizing in September and October (Table 1). Rising silica concentrations during June and July preceded the onset of the diatom bloom which dominated the phytoplankton community most of the year (Section 4.4.1). Diatoms utilize silica in the construction of their frustules, so the decline in silica levels documented during the diatom bloom was typical (Klemer and Barko, 1991).

*Chlorophyll* a

In early June, chlorophyll *a* concentrations were lowest in the southern two-thirds of the lake (0.09 - 0.14 μg/L), with patches of higher concentrations (0.14-0.19 μg/L) southeast of Chiefs Island and in the northern half of the lake. The highest concentrations (0.19 to 0.24 μg/L) were found along the nearshore between Quarry Bay and Floral Point. Among the nearshore stations, values ranged from trace amounts to 2.6 μg/L in June, and from trace to 1.6 μg/L in July among the nearshore stations. Among the mid-lake stations, chlorophyll *a* concentrations ranged from 0.5 to 2.6 μg/L (Figure 5). At all four mid-lake stations, chlorophyll *a* concentrations peaked in mid-July and were at their lowest through late August and September. Based on the observed chlorophyll *a* concentrations, Lake Couchiching can be classified as oligotrophic to slightly mesotrophic. Carleton (1977) classified lakes with summer average chlorophyll *a* concentrations of between 1 and 6.4 μg/L as mesotrophic.

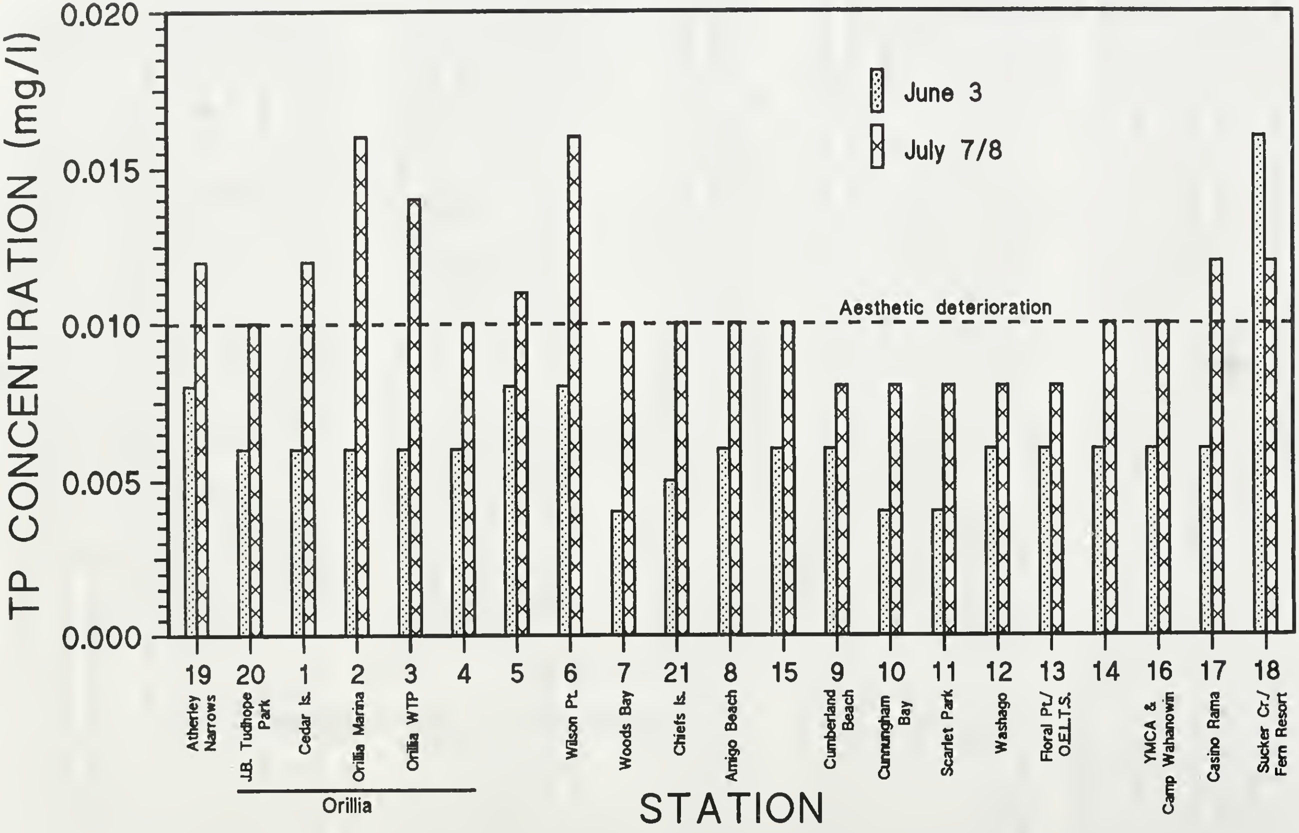

Figure 6. Spatial variations in total phosphorus concentrations in Lake Couchiching on June 3 and July 7/8.

### 4.2.5 Bacteria

Bacteria were detected infrequently and at low densities in Lake Couchiching. The highest density or concentration of the indicator *Escherichia coli*, 36 organisms per 100 ml at Station 1 near Cedar Island, was well below the PWQO (OMOEE, 1994b) of 100 organisms per 100 ml for the protection of recreational water users. These data are consistent with historical findings (Katona, 1998). Faecal *Streptococcus* was detected at a maximum density of 18 organisms per 100 ml, again at Station 1 near Cedar Point. There is currently no limit for the numbers of faecal streptococci (CCME, 1991). The pathogen *Pseudomonas aeruginosa* was not detected in any of the samples (Appendix D). Based on these data for faecal coliforms, there is no apparent risk of infection by swimming in Lake Couchiching.

### 4.2.6 Taste and Odour Problems

Residents of Orillia have complained about poor taste and odour of municipal water supplies originating from Lake Couchiching. Taste and odour problems have been attributed to two compounds (geosmin, or 1,10-trans-dimethyl-trans-9-decalol, and 2-MIB or 2-methylisoborneol) that originate primarily in algae (Katona, 1998). Previous work has shown that algal densities in the water column of Lake Couchiching are below thresholds that would cause taste and odour problems (Katona, 1998). It has been suggested, however, that green and blue-green algae that reside on the bottom of the lake may be responsible for the poor taste and adour. Indirectly, the introduction of zebra mussels to the lake may be responsible for the poor taste and odour. Where zebra mussels colonize, densities of benthic algae have been shown to increase (Lowe and Pillsbury, 1995). Zebra mussels have colonized virtually every location within the lake and this survey did document obvious growths of benthic algae (Section 4.4).

### 4.2.7 Metals

Metal levels in Lake Couchiching water were very low and averaged from one (e.g., cadmium) to four orders of magnitude (e.g., beryllium) lower than their respective Provincial Water Quality Objectives (PWQOs) (Appendix D). Only one duplicate sample of mercury from Station 21 in June (0.25 $\mu$g/L) slightly exceeded the PWQO of 0.2 $\mu$g/L.

### 4.2.8 Organic Contaminants

Of the 30 organic compounds for which water samples were screened, only atrazine was found at 'trace' levels of 66 to 140 ng/L, in 15 of the 24 samples collected (Appendix D). No phenoxy acid herbicides or chlorophenols were detected in Lake Couchiching water. Atrazine was detected at "trace" amounts (i.e., less than 150 mg/L in over half of the water samples, with most of the detections occurring along the western shore where temperatures were warmer. Atrazine has a short half life and probably originates from agricultural runoff. Surface runoff from agricultural landscapes should be warmer than typical stream runoff. Both higher temperatures and trace amounts of atrazine therefore suggest that runoff from agricultural areas are being introduced to the lake along the western shore. Concentrations of atrazine were below levels that pose ecological or human health risks. The federal water quality guideline for the protection of aquatic life is set at1800 ng/L, while the federal drinking water objective is set at 5000 ng/L (CCME, 1991).

### 4.3 Sediment Characteristics and Quality

Sediment chemistry data from this study (Appendices E, F) were compared to the Provincial Sediment Quality Guidelines (PSQG; Persaud *et al.*, 1993) as well as to data from deeper layers of the cores obtained from Stations 5 and 15, which should represent background levels for the inorganic contaminants in this system.

#### 4.3.1 Core Sediments from Stations 5 and 15

Visual, olfactory and chemical characteristics of the surface (0-5 cm) sections from cores collected at stations in the middle and southern basin of the lake were generally consistent with the information obtained from the surficial sediment samples. Surface layers at Stations 5 and 15 consisted of a gray or gray-brown, watery ooze (Appendix F). At Station 5, where an odour of rotten eggs was given off by the surface sediment, this odour persisted to a depth of 35-45 cm. At ~95 cm depth a gray clay or clay-like material appeared. Moisture content of the sediments decreased from 74-75 % in the surface (0-5 cm) layers, to 47-51 % at depths of a metre or more, probably due to compaction. Below 15 cm depth, white particles of marl (calcium carbonate) were evident, and snail or clam shells or fragments were also found in some sediment layers. Microscopic and size distribution analysis by sieving indicated that medium to fine sand, and silt and clay predominated in the sediments, with fine particles of less than 63-$\mu$m diameter (silt and clay) usually contributing 50 % or more of the sediment.

Calcium, magnesium, aluminum, barium, cobalt, iron, manganese and strontium concentrations were relatively constant with depth, whereas titanium increased slightly in deeper sediment. In contrast, concentrations of chloride, cadmium, copper, lead, zinc and mercury increased markedly in more recently deposited (upper 15-25 cm) sediments (Figures 7, 8). The core sections were not dated for this study, so no age in terms of years can be assigned to the different layers of the cores. Nevertheless, increased levels of chloride in surface sediments probably reflect urban development and increasing use of road salt. Similar increasing trends in chloride levels in water from Lake Simcoe have been shown (LSRCA et al., 1995). An increase in lead levels in surficial sediments is a typical result because of the historic use of leaded gasoline. Cadmium, copper, lead and zinc can also be contributed from urban areas (Klassen, 1992; Schueler, 1992). In neighbouring Lake Simcoe, mercury contamination originates from sanitary landfill sites, sewage sludge disposal areas, urban stormwater runoff, golf courses that use mercurial fungicides, and atmospheric sources. Natural geologic sources and contributions from intensive agriculture in the Holland Marsh have been shown to be insignificant (OMOE, 1978).

The average chemical concentrations in the lower sections (> 25 cm depth) of cores from Stations 5 and 15 were used as an additional comparison or reference for the concentrations found in surface (top 5 cm) sediments from stations in shallower waters of the lake.

#### 4.3.2 Spatial Survey of Surficial (Recent) Sediments

Observations of the sediment samples indicated that the uppermost layer (surface) of sediment at most of the 21 sampling stations consisted of silty ooze. Rooted aquatic plants - particularly calcified *Chara* - were also present at all stations but 5, 15 and 17. No oil or petroleum odour was detected at any of the stations, but a number of them, particularly those situated in the southwest end of the

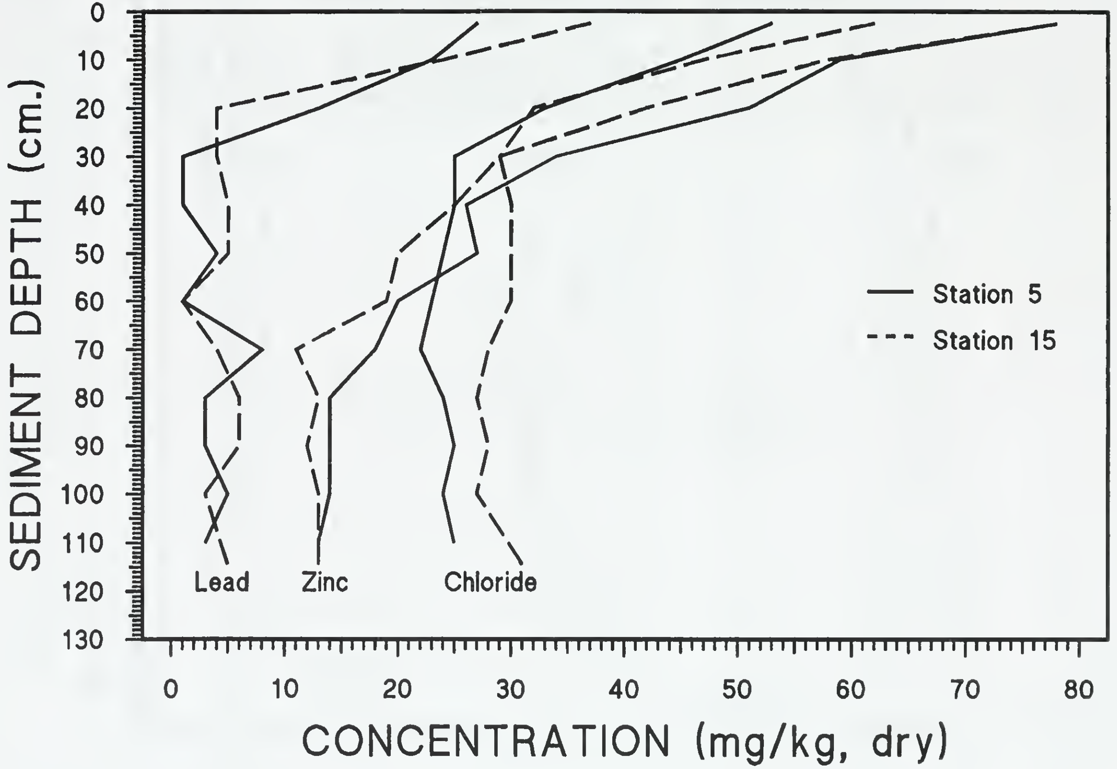

Figure 7. Concentrations of chloride, zinc and lead with increasing depth at Stations 5 and 15 in Lake Couchiching.

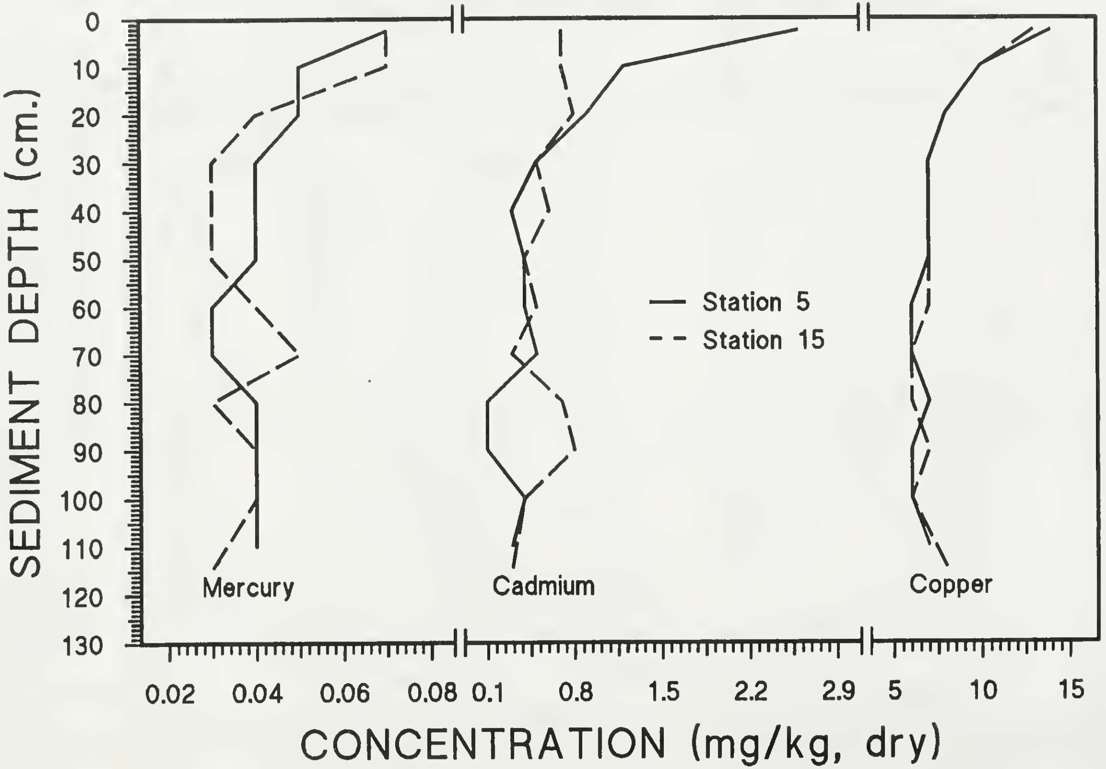

Figure 8. Concentrations of mercury, cadmium and copper with increasing depth at Stations 5 and 15 in Lake Couchiching.

lake near Orillia, had sediments which gave off a rotten egg (hydrogen sulphide) odour. Microscopic examination of these surface sediment samples showed that the majority of the sediment was composed of sand, silt and clay (carbonates and quartz), with the balance contributed by shell debris, vegetation fibres and fossilized plant material. Particle size analysis by sieving also indicated that sand, silt and clay predominated in the sediments, with fine material of less than 63-$\mu$m diameter (silt and clay) usually contributing 50 % or more of the sediment. Exceptions to this were found at Stations 10, 13, 14, and 18, where sand predominated.

The major elemental composition of a few of these samples was determined using X-ray diffraction spectroscopy. In all cases, the principal cation was calcium, followed by aluminum, iron, potassium and silica. Macro-ion and trace metals analysis of the sediment samples also indicated this trend; namely, calcium was present at the highest concentrations (77,000-210,000 mg/kg, or 7.7-21 %, by dry weight), followed by iron, aluminum, magnesium, titanium, manganese and strontium (Appendix F).

Overall, inorganic and heavy metal contaminant levels were quite low in the surface sediment samples from Lake Couchiching. The average concentrations of arsenic and selected metals for all 21 stations sampled are given below:

| Element | Average (mg/kg) | Element | Average (mg/Kg) |
|---|---|---|---|
| arsenic | 1.8 | manganese | 232 |
| cadmium | 0.5 | mercury | 0.02 |
| chromium | 11 | nickel | 7.6 |
| copper | 7 | selenium | 0.5 |
| lead | 20 | zinc | 35 |

Comparison of the surface sediment arsenic and heavy metal concentrations with the "background" concentrations derived from deeper layers of sediment cores (Section 4.3.1) revealed those locations with levels above the "background" for the lake. These stations included:

| Element | Stations above background | Element | Stations above background |
|---|---|---|---|
| arsenic | all but 10, 13, 18 | manganese | 14, 17 |
| aluminum | 1, 15 | molybdenum | 1, 2 |

| Element | Stations above background | Element | Stations above background |
|---|---|---|---|
| antimony | 1 to 7 | nickel | 1, 5, 15 to 17 |
| barium | 1 | selenium | 1 to 5, 7, 11, 14 to 17, 19 |
| cadmium | 1, 5 | strontium | 2 to 5, 7, 11, 12, 16, 17, 19 |
| chromium | 1, 5, 15 | titanium | 1, 10, 11, 18 |
| cobalt | 1, 15 | vanadium | 1, 15, 18 |
| copper | 1 to 5, 15, 17 | zinc | 1 to 5, 14, 15, 17, 19, 20 |
| lead | 1 to 8, 11, 12, 14 to 17, 19 to 21 | | |

Anthropogenic contamination by metals was therefore most evident at stations in the vicinity of Orillia, likely reflecting inputs such as surface runoff from urban areas (Figures 9, 10). However, with the exception of cadmium, surficial metal concentrations were all well below (by factors of up to 10) the respective PSQG Lowest Effect Level (LEL) for the protection of sediment-dwelling organisms (benthic invertebrates) (Persaud et al., 1993). LELs are the concentrations above which more than 5% of the sediment-dwelling benthic taxa can be expected to be impacted (Persaud et al., 1993). The average concentration of cadmium, 0.5 mg/kg, was only just below the PSQG-LEL of 0.6 mg/kg, due in part to high concentrations Stations 1, 3, 5, 15 and 17 (Figure 10). In addition, a few stations had concentrations of one or more of these metals above their respective guidelines. This was most evident at Station 1, just off the Orillia marina, where a variety of metals were in excess of the PSQG LEL. These included arsenic (9.5 mg/kg, LEL = 6 mg/kg), cadmium (1.9 mg/kg, LEL=0.6 mg/kg), chromium (55 mg/kg, LEL=26 mg/kg), copper (22 mg/kg, LEL=16 mg/kg), lead (58 mg/kg, LEL=31 mg/kg) and nickel (28 mg/kg, LEL=16 mg/kg) (Figures 9, 10, Appendix F). Nevertheless, these concentrations were all well below the PSQG Severe Effect Levels (SELs) for these contaminants. SELs are the concentrations above which effects can be expected on more than 95% of sediment-dwelling benthic taxa (Persaud et al., 1993).

Even though metal concentrations were low, there was evidence that at least mercury is biologically available and biomagnifies in the food chain in Lake Couchiching. Routine monitoring by the OMOEE (1997) shows that mercury levels in large specimens of smallmouth bass, largemouth bass, northern pike, walleye and yellow perch are elevated, with resultant consumption restrictions for people. In Lake Simcoe, there have been no changes in mercury concentrations in cisco, whitefish or perch since 1928.

Although nutrient concentrations increased marginally in surficial sediments relative to background concentrations, historical concentrations have generally naturally exceeded PSQGs LELs (Appendix E). For example, the LEL for total Kjeldahl nitrogen (TKN) is 0.55 g/kg. Surficial concentrations of TKN averaged 3.0 and ranged from 0.7 to 4.9 g/kg (Figure 11). However, core data show that

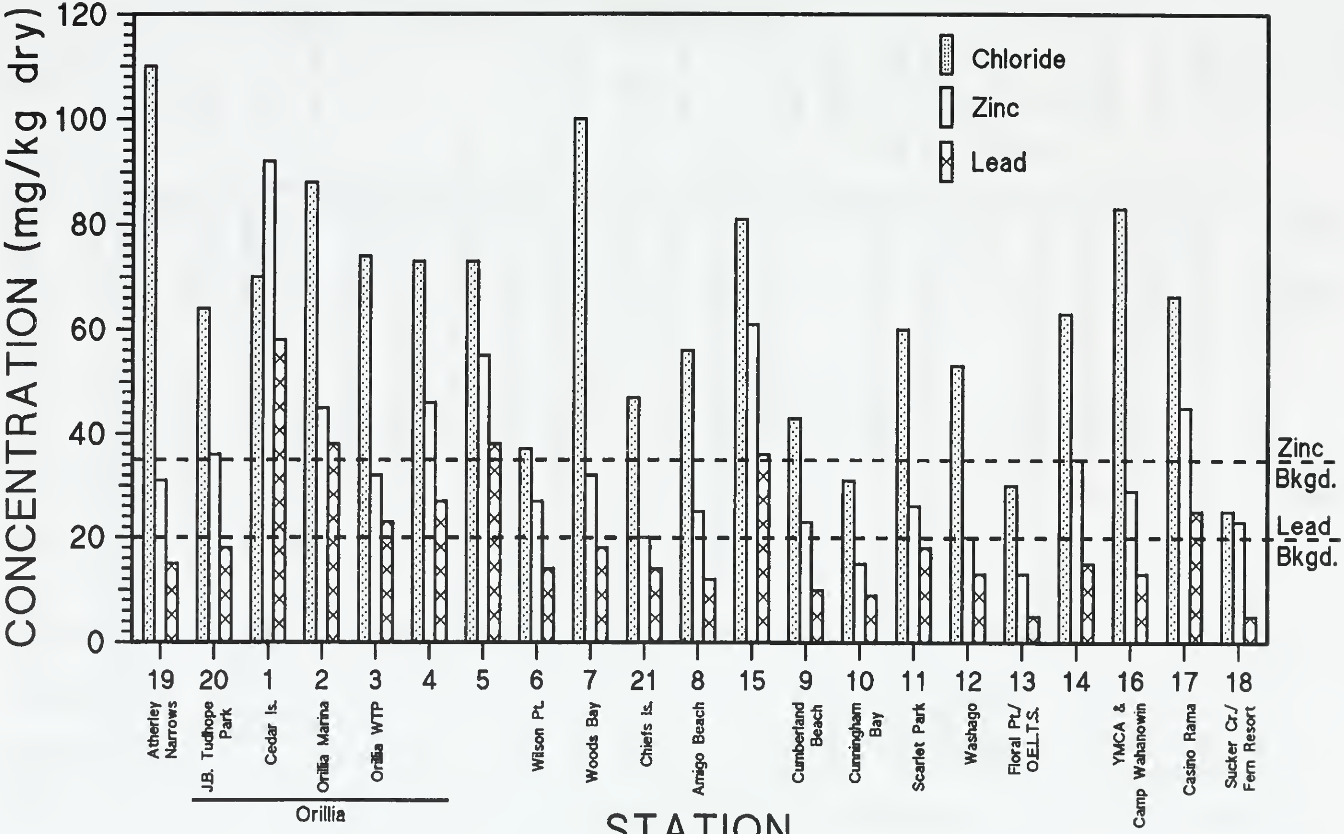

Figure 9. Spatial variations in surficial sediment concentrations of chloride, zinc and lead in Lake Couchiching. "Bkgd" = background concentrations from deep cores from Stations 5 and 15.

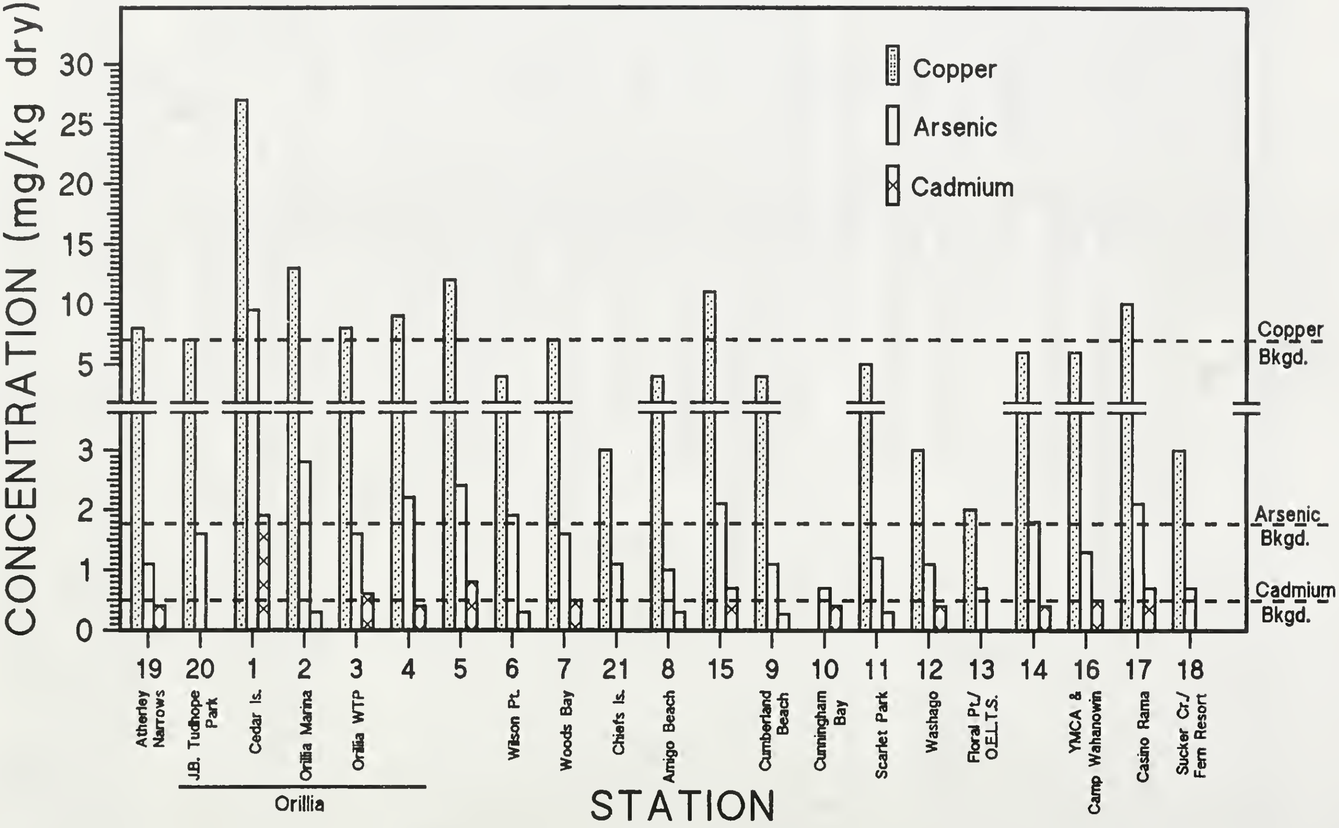

Figure 10. Spatial variations in surficial sediment concentrations of copper, arsenic and cadmium in Lake Couchiching. “Bkgd” = background concentrations from deep cores from Stations 5 and 15.

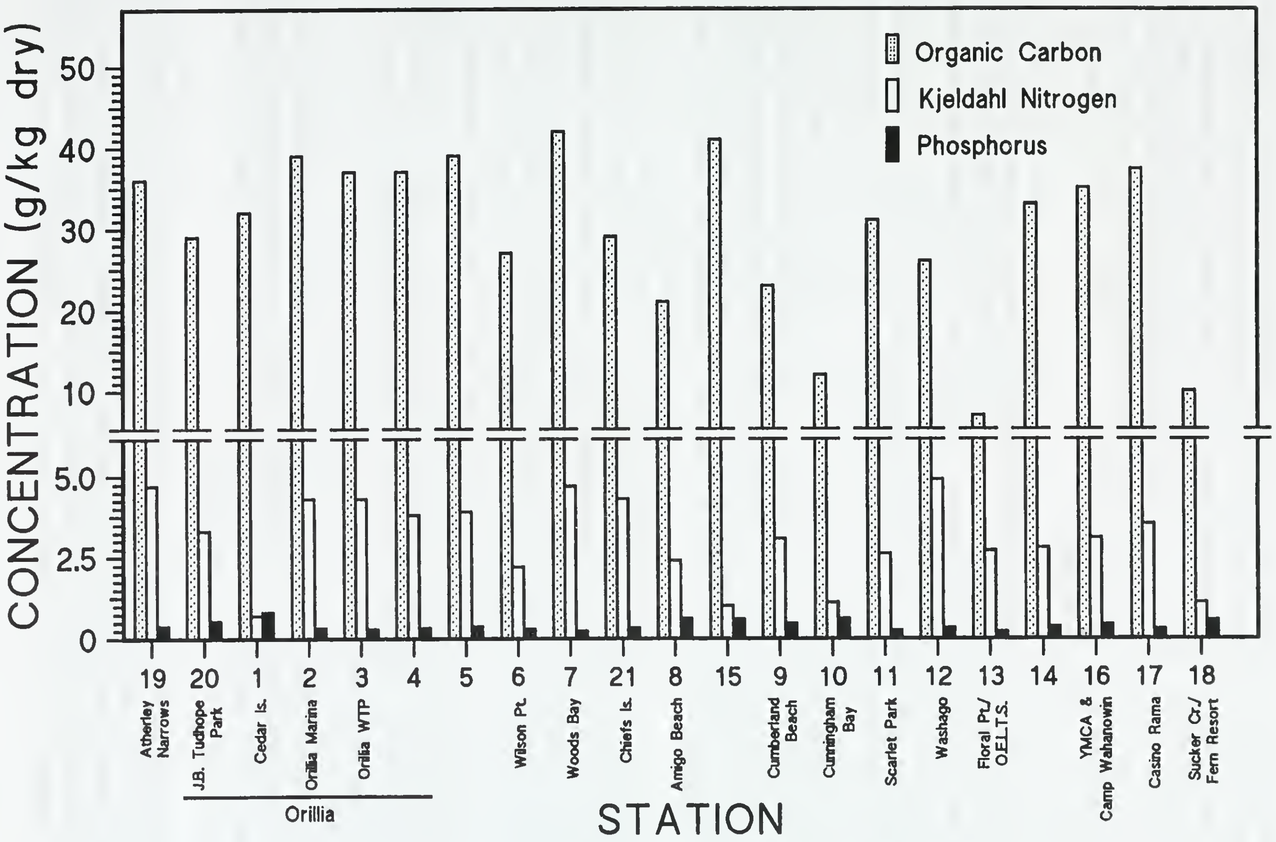

Figure 11. Spatial variations in organic carbon, Kjeldahl nitrogen and phosphorus concentrations in surficial sediments.

TKN concentrations were originally about 1 g/kg (Appendix E). Results for total organic carbon (TOC) are similar. The LEL for TOC is 1% or 10 g/kg. Concentrations of TOC in surficial sediments averaged 30 g/kg and ranged from 7 to 42 g/kg (Figure 11). Core data show that TOC concentrations were originally about 25-30 g/kg (Appendix E). Finally, phosphorus concentrations in surficial sediments have increased from historical concentrations of about 0.1 to 0.2 g/kg, to 0.3 g/kg (Figure 11). The PSQG LEL for phosphorus in sediments is 0.6 g/kg. As a result, phosphorus in sediments has been, and continues to be within acceptable limits. None of the nutrients exceed PSQG SEL concentrations (Appendix E).

Polycyclic aromatic hydrocarbons (PAHs) were detected at low concentrations in a few of the Lake Couchiching surface sediment samples. These were congregated in the south-west end near Orillia (Stations 1, 2, 3, 4 and 5) and at Stations14, 15, 17, 18, 19 and 20. Of the 16 compounds analyzed for, eleven (benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)-fluoranthene, benzo(g,h,i)perylene, benzo(a)pyrene, chrysene, fluoranthene, indeno(1,2,3,-cd)pyrene, naphthalene, phenanthrene and pyrene) were detected at one or more stations. Fluoranthene, indeno(1,2,3-cd)pyrene and pyrene were detected most frequently, i.e., at six to seven of the 21 stations. These included four stations at the south-west end of the lake (Stations 1 to 4), and the two in the deeper basins (Stations 5 and 15). With one exception however, concentrations of the individual compounds, as well as of total PAHs were below the respective PSQG-LELs. At Station 1, the concentration of indeno(1,2,3-cd)pyrene (240 $\mu$g/kg) was slightly above the PSQG-LEL of 200 $\mu$g/kg. Due to the relatively low PAH concentrations, core sections from Stations 5 and 15 were not analyzed for these compounds.

One surface sediment sample, from Station 2, off the Orillia water treatment plant intake and just north of the Orillia marina, was also analyzed for polychlorinated dibenzo-*p*-dioxins and furans (PCDD/Fs). Results indicated low concentrations of the different homolog groups, ranging from 5.6 ng/kg PentaCDD to 150 ng/kg for OctaCDD. The homolog distribution pattern is typical of combustion sources (Rappe, 1994). Concentrations of the toxic (2,3,7,8-substituted) isomers ranged from 1.3 ng/kg for 1,2,3,4,7,8-HexaCDF to 29 ng/kg for 1,2,3,4,6,7,8-HeptaCDD. The calculated 2,3,7,8-Tetra CDD Toxic Equivalence (TEQ) was 4.3 ng/kg, which is in the background range for the Great Lakes Basin (Reiner, OMOE LSB, pers. comm, 1998). This TEQ was obtained by multiplying the individual isomer concentrations by their respective International Toxic Equivalence Factor (I-TEF), which ranks toxicity relative to that of the most toxic isomer, 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin, assigned an I-TEF of 1.

Other persistent organic contaminants, including PCBs, organochlorine pesticides, phenoxy acid herbicides, chlorinated phenols, and chlorinated aliphatics and aromatics, were not detected in any of the Lake Couchiching surface sediment samples. Consequently, core sections from stations 5 and 15 were not analyzed for these contaminants.

Solvent extractables (a measure of fats, oils and greases, both natural and man-made) in surface sediments of the lake averaged 1074 mg/kg and ranged from 370 to 2200 mg/kg (Appendix E). No PSQG for the protection of benthic invertebrates is available to interpret these concentrations. However the Open Water Dredged Material Disposal Guideline of 1500 mg/kg can be used for comparison. Levels at six of the 21 stations were at or above this guideline. Four of these stations

(1 to 4) were in the south-west end of the lake, near Orillia; the remaining two were in Woods Bay (Station 7) and off James B. Tudhope Park, near Old Brewery Bay (Station 20). It should be noted that no petroleum hydrocarbons were found in any sediments from the lake (Method Detection Limit of 100 mg/kg), suggesting that the solvent extractables found in samples represent natural sources, such as lipids and fats resulting from decomposing plant and animal matter.

## 4.4 Plankton

### 4.4.1 Phytoplankton

The phytoplankton community was represented by 54 genera from six classes. No representatives of the Euglenophyta were found (Appendix G). Two marked periods of succession were observed (Figure 12). The chrysophyte, *Dinobryon sp.*, was the clear dominant of the early summer followed by *Uroglena sp.* This was followed by a clear genus shift which occurred in late July. *Uroglena sp.* replaced *Dinobryon sp.*. The Bacillariophytes (diatoms) dominated the community through the rest of the summer (Appendix G). *Rhizosolenia sp.* and *Cyclotella sp.*, were co-dominant in early August through September, when *Cyclotella sp.*, became the dominant diatom for the remainder of the year.

Through the early season the chrysophytes made up almost 95% of the community composition, but by mid-summer diatoms made up almost 71% of the community. Lake Couchiching phytoplankton communities were almost identical at the four mid-lake stations (Appendix G). Chrysophytes and diatoms were the dominant classes, and biovolumes were highest at Stations 5 and 15. Diatoms ranged in dominance between 27% and 43% of the population, while Chrysophytes ranged between 43% and 56% of the community composition (Appendix G).

Phytoplankton communities were generally similar among the open-lake stations, reflecting generally homogeneous water chemistry. Although Station 5 (nearest Orillia) had marginally higher nutrient levels, algal community composition was similar to the other three stations. Total algal biovolume at Station 5 was however approximately twice as high as at Stations 12 and 21 (Appendix G). At all stations, biovolumes were low, so nuisance algal levels were not observed.

Seasonal succession of algal communities in Lake Couchiching was markedly different from successions observed in more eutrophic areas such as Penetang Bay, (Gemza 1995a), (which is situated at the western extreme of the Severn River into which L. Couchiching empties) and Saginaw Bay, Lake Huron (Stoermer and Theriot 1985). In Saginaw Bay, diatoms bloom are dominant in spring, while dinophytes, chlorophytes and cryptophytes are dominant in the summer, and blue-green algae are dominant in the fall. In Penetang Bay of Severn Sound, *Melosira* sp. dominate the algal community, reflecting eutrophic conditions. In contrast, the diatom community in Lake Couchiching is dominated by *Cyclotella sp.*, which is usually associated with oligotrophic conditions.

### 4.4.2 Zooplankton

Zooplankton were represented by 15 species (Appendix H). Biomass peaked in mid June (84 mg/m$^3$), coincident with the clear water phase (Figure 13). A second biomass peak occurred in early September when the community was dominated by the calanoid, *Skistodiaptomus oregonensis.* Cyclopoid copepods (primarily *Diacyclops thomasii*) made up over 70% of the zooplankton community at that time. The zooplankton were composed primarily of calanoid and cyclopoid

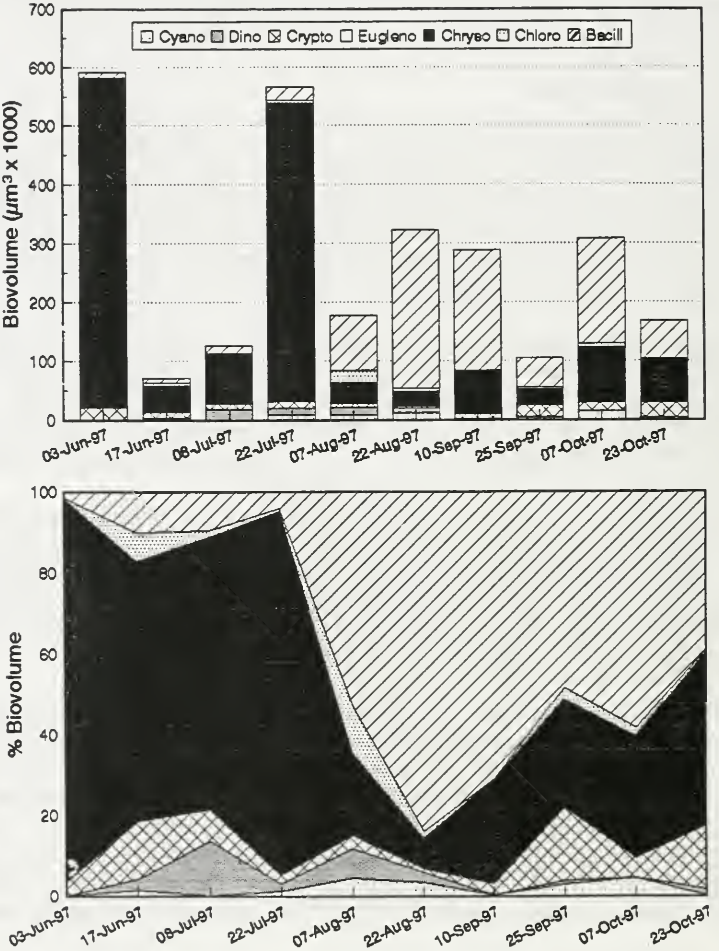

Figure 12. Seasonal trends in algal community composition at Station 5 in Lake Couchiching during 1997.

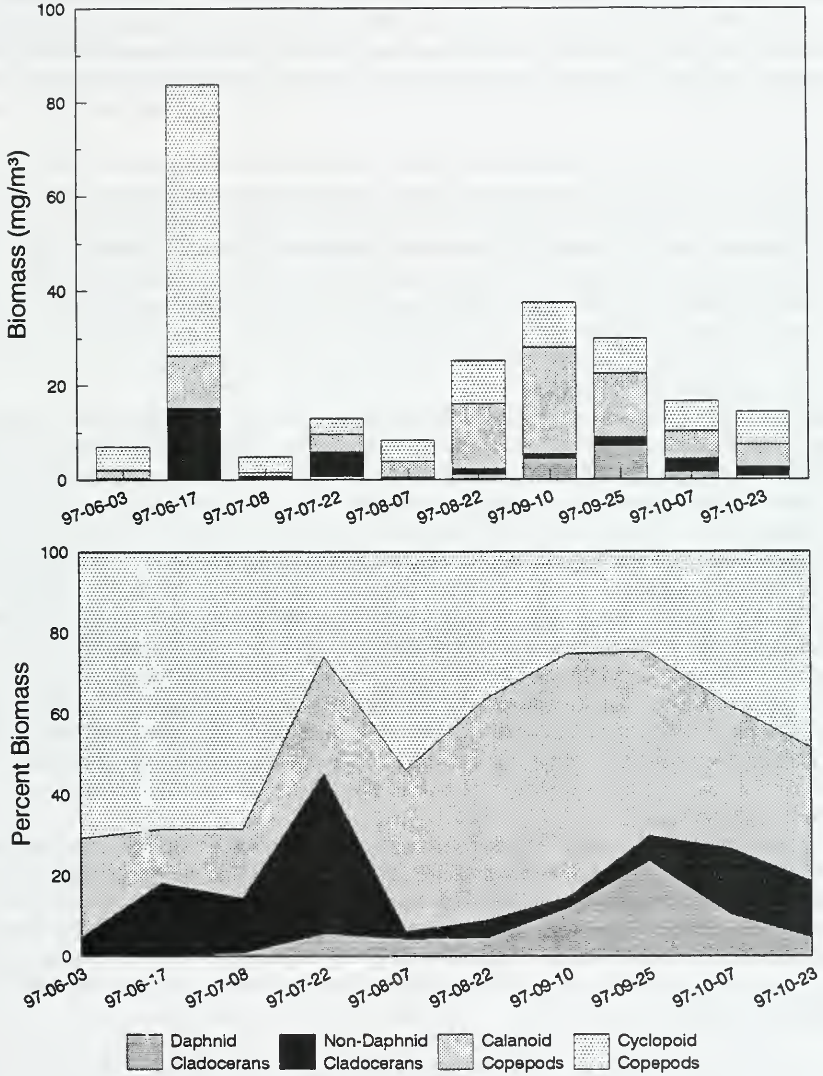

Figure 13. Seasonal zooplankton succession at Station 5 in Lake Couchiching, 1997.

copepods and non-daphnid cladocerans (*Bosmina longirostris*). Daphnid cladocerans made up almost 24% of the community in late September but usually constituted less than 10% of the community (Appendix H). The calanoid copepods, primarily *Leptodiaptomus minutus* and *Skistodiaptomus oregonensis*, succeeded the cyclopoids and non-daphnid cladocerans by early August (Appendix H).

In Lake Couchiching, zooplankton community composition was also characteristic of oligotrophic conditions. Increasing zooplankton biomass with increasing lake eutrophy is a well established phenomenon (Pace 1986). Eutrophic systems typically are dominated by smaller-bodied non-daphnid cladocerans such as *Bosmina spp.*, as well. Both trends indicating eutrophy were observed in Penetang Bay and across Severn Sound (Gemza 1995 b). Compared to eutrophic Penetang Bay where zooplankton biomass typically peaked at over 400 mg/m$^3$, zooplankton biomass in L. Couchiching only reached peaks near 80 mg/m$^3$, and typically ranged between 5 and 37 mg/m$^3$.

### 4.4.3 Zebra Mussel Veliger Larvae

Zebra mussels (*Dreissena polymorpha*) have a planktonic larval (veliger) stage. Between 1992 and 1995, the Ontario Ministry of Natural Resources (Lake Simcoe Fisheries Assessment Unit) monitored Lake Couchiching for the presence of zebra mussel veligers. The results of those surveys have yet to be released by the Ministry. During this 1997 survey, zooplankton collection utilized 80-$\mu$m mesh which is small enough to collect later-stage veliger larvae (larvae remain in the water column until they are about 200-$\mu$m long). In this survey, veliger larvae were first observed in the samples on June 17. On July 9, veliger larvae exceeded the biomass of other zooplankters (Appendix H). Of a total zooplankton biomass of about 18 mg/m$^3$, veligers constituted about 14 mg/m$^3$ of the total, with a density of over 16,000 veligers per m$^3$. On August 7 , the biomass of veliger larvae fell to about 9 mg/m$^3$. Through the remainder of the summer, veligers gradually fell in importance from about 40% of the zooplankton biomass to less than 20% (4.2 mg/m$^3$) by August 22. By September the planktonic veliger constituted less than 1% of the equivalent zooplankton biomass. Peak veliger densities were measured during the spring clear water phase, evident through June and July.

## 4.5 Macroflora

Aquatic macroflora (macroalgae and macrophytes) are important to lake systems because they provide food and habitat for fish and wildlife, cycle nutrients, assist in thermal regulation of the lake, are aesthetically appealing, and stabilize lake sediments (provide protection from wind-induced scour). In excess, macroflora can be detrimental by impeding boating and swimming, fouling shorelines with large mats of plant debris, and can cause degraded water quality as a result of decomposing organic matter (oxygen depletion) in bottom waters, and taste and odour problems in drinking water.

In Lake Couchiching, the macroalga *Chara* was the single most dominant form at 19 of 21 sampling locations. *Chara* was absent only at Stations 5 and 15 where water depths were 7 and 9 m respectively. At these two deeper stations, only the filamentous alga *Cladophora* was found. When found, beds of *Chara* were up to 50 cm tall (Appendix I). *Vallisneria americana*, (tape grass, wild celery), *Utricularia vulgaris* (bladderwort), *Najas flexilis* (bushy pondweed) and *Potamogeton richardsonii* (Richardsons pondweed) were also present at many stations (Appendix I). Broadleaf forms of *Potamogeton* (*P. amphipolius*), *Elodea canadensis* (common waterweed) and *Myriophyllum spp*. (Eurasian Water Milfoil) were found at a few stations each (Appendix I). The presence of *Najas flexilis* (bushy pondweed) increased significantly between July and August. Fragments of this plant were commonly observed floating on the surface of the lake in August , and a wind row 1m wide and approximately 15 cm thick was observed fouling the beach near the Orillia water treatment plant.

The plant growth in nearshore areas and around islands was variable. Luxuriant growths of *Vallisneria americana* and *Elodea canadensis* and *Spirogyra* (a filamentous green alga) were present near the marina at Orillia. This area is sheltered by break walls that reduce wave action and receives stormwater discharges from Orillia. *Myriophyllum spicatum* was growing in the south end of the lake, especially near the Narrows in the areas receiving incoming flows from Lake Simcoe. Heavy growths in the Narrows area interfered with the operation of the boat. The shallow sand areas around Chiefs Island were void of plants in many areas or produced sparse growths of *Chara sp*.

The three depth sounder transects further characterized the dominance of the macrophyte *Chara* at depths between 1 and 6 m. Only the filamentous green alga *Cladophora* and the odd plant sprig was documented by grapnel in depths greater than 6 metres. While the depth sounder recorded nearly continuous plant growths over the bottom in depths less than 6 m, it also documented that plant growths did not reach the surface in the open sections of the lake. Luxuriant plant growth in nearshore areas appeared to be limited to narrow bands and patches. The dominant plants, *Chara* and *Vallisneria americana* are not nuisance plants. *Chara* grows on the bottom, and is rarely found in the upper water column. The ribbon-like leaves of *Vallisneria americana* sometimes reach the surface, but usually only the slender coiled flower stalks are present on the surface in August.

The presence of the filamentous green alga *Spirogyra* was commonly noted in the south portion of the lake. This plant grew on (fouled) the aquatic macrophytes and *Chara sp*. beds. Large billowy clouds of this alga were present on the sandy substrates near the breakwalls around the marina at Orillia and in the bay areas between the marina and the narrows near the incoming flows from Lake Simcoe (Figure 14). Past plant studies by Veal and Jones (1972) did not document significant growths of *Spirogyra*. Large growths of filamentous green algae (i.e., *Spirogyra*)can result in water quality problems including loss of recreational potential (i.e., swimming) and loss of habitat for fish and wildlife (fouling of plant beds and bottom substrate). Large amounts of *Spirogyra* and other filamentous green algae also have the potential to reduce dissolved oxygen levels during night time, due to respiration.

During the plant survey, large numbers of zebra mussels were observed throughout the lake . Small mussels from 2 to 10 mm long were commonly found on macrophytes, particularly *Chara sp*. In 1972, *Myriophyllum* was the single most dominant (79% of stations) and abundant plant (Veal and Jones, 1972). *Chara*, *Vallisneria americana* and *Najas flexilis* were less abundant, but still prevalent. In 1997, *Myriophyllum* was not abundant or prevalent, being found at only a single station (19) at the inflow of Lake Couchiching. In 1972, the species of *Myriophyllum* was probably *M. spicatum* (Eurasian Water Milfoil). This exotic plant clogged several lakes in Southern Ontario with growths impeding operation of water craft (Wile et al., 1979). At some lakes, mechanical harvesting was

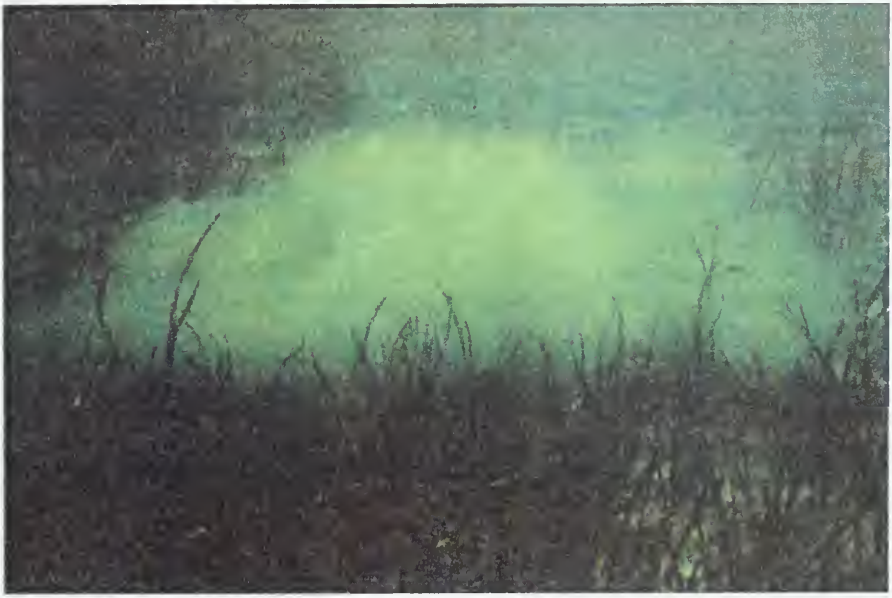

Figure 14. Underwater photo of a benthic algal growth at Station 2 in Lake Couchiching

implemented to cut channels for boat access through the plant beds (e.g., in Rondeau Bay, Lake Erie, Chemong Lake). The movement (invasion) of this plant into Southern Ontario was underway in 1971 (Chemong Lake) and peaked in the late 1970's. The decline in abundance of *Myriophyllum* in Lake Couchiching is typical. This plant has similarly disappeared from or declined in other lakes in Ontario and the north western United States (Aiken et al., 1979; Carter, 1979).

*Scirpus acutus* (hardstem bullrush) was present in many shallow (less than 1 m depth), sandy, nearshore and island areas of the lake. Large beds of this plant were present around Chiefs Island and in the south end of the lake in the vicinity of the narrows. No attempt was made to sample or totally quantify the presence of this emergent plant. These observations are similar to those by Veal and Jones (1972).

Overall, the aquatic macroflora study documented a healthy plant community in Lake Couchiching dominated by the native plants *Chara sp.*, *Vallisneria americana*, *Najas flexilis* and *Utricularia vulgaris*. These plants provide food and habitat for fish and wildlife and provide many water quality benefits (e.g., increased water clarity and algae control). They are present throughout the lake with the exception of the two deep basins (where insufficient light reaches the bottom) which are located to the north and south of Chiefs Island. These deeper areas (greater than 6m in depth) had a thin layer of filamentous green alga *Cladophora sp.* on the surface of the silt, muck substrate.

### 4.6 Benthic Macroinvertebrates

This study documented 96 distinct taxa from 22 major taxonomic groups (Appendix L). In general, most samples contained the common amphipod *Hyalella azteca*, a good variety of chironomids (midges), the mayfly *Caenis punctata*, a few Leptoceridae (Trichoptera), an assortment of gastropod molluscs (snails) and a large number of adult zebra mussels (*Dreissena polymorpha*) (Appendix J, Figure 15). The generally uniform substrate of silty sand, with a high mollusc shell content and dense mat of the aquatic plant *Chara* was probably responsible for the generally uniform benthos. Total numbers of benthos ranged from just over 7,000 $m^{-2}$ to just under 100,000 $m^{-2}$ (Appendix J), while the number of taxa per sample ranged from 14 to 28. Diversity was relatively high, ranging from 1.98 at one of the deeper stations (Station 5) to 3.68 at Station 4.

None of the benthos found in the lake were unusual, although the dominant mayfly in the lake (*Caenis punctata*, Provonsha, 1990) is of interest taxonomically. Specimens from Lake Couchiching have features that resemble *Caenis youngi*, and were similar to specimens observed near Sault Ste. Marie (Morton, pers. comm.). Provonsha (pers. comm.) suggests that those with similarities to both *C. punctata* and *C. youngi* may actually be the undescribed nymphs of *Caenis candida*.

Zebra mussels were dominant members of the benthic community at all stations (Figure 15) with numbers ranging as high as 60,000 $m^{-2}$ (Appendix J). Most of these zebra mussels were associated with *Chara*, actually being attached to the macroalga. So far, abundances of zebra mussels in Lake Couchiching are not extraordinary. Zebra mussel populations have exceeded 200,000 $m^{-2}$ on hard substrate in Lake Erie (Dermott et al., 1993), but are typically lower (10,000 $m^{-2}$) on soft substrate (e.g., Griffiths, 1993).

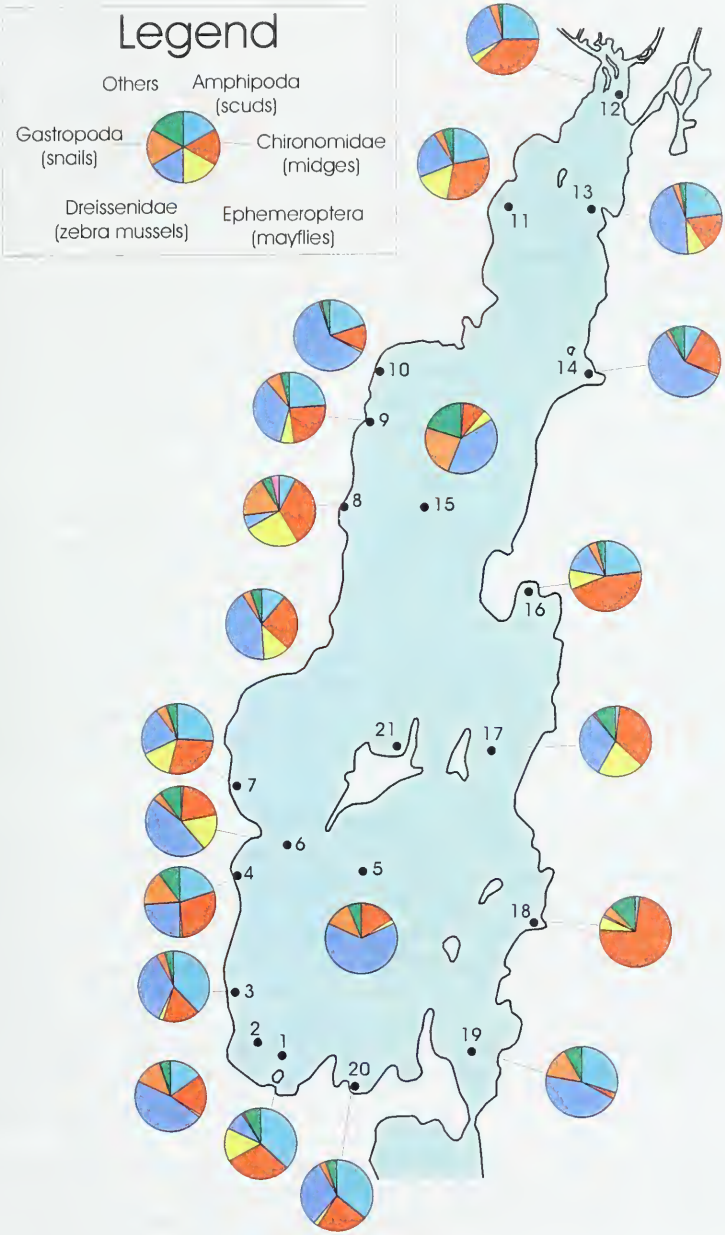

Figure 15. Map of Lake Couchiching showing the percent composition of major groups of benthic macroinvertebrates at each station in 1997.

The arrival of zebra mussels in Lake Couchiching has the potential to alter both biological and physico-chemical aspects of the lake. The date of entry of zebra mussels into the lake has not been confirmed (Ron Allan, OMNR, Lake Simcoe Fisheries Assessment Unit, pers. comm.). However, some of the "baseline" characteristics described in this survey may already reflect the presence of zebra mussels. The change in lake clarity since 1977 is a good example (Section 4.2.3). Such changes in clarity are typically followed by effects on local sediments and fauna. For example, in Lake Erie, increased clarity has caused walleye to seek deeper (darker) water. In addition, the filtering ability of zebra mussels shifts a lot of energy from the water column to the sediments where it is more available to benthic organisms. In Lake St. Clair, increased water clarity is considered one reason plant growths have increased (Griffiths, 1993). In Lake Erie, Dermott et al. (1993) demonstrated that benthic communities in the vicinity of zebra mussels were more abundant. Via production of pseudofaeces, zebra mussels also have the potential to alter sediment type (make sediments finer) and increase contaminant concentrations in sediments (Howell et al., 1996).

Most of these effects on fish, plants and small benthos are fairly subtle in relation to the effects zebra mussels have on large Unionidae. Unionids are large bivalves that live in soft sediments, and like zebra mussels, filter water. In Lake Couchiching, the single species of unionid bivalve identified in the survey was *Lampsilis radiata* (Appendix L). Specimens of *L. radiata* were found at Stations 13 and 15 using the Ponar grab. Specimens were also observed (but not collected in the Ponar samples) at Station 21. At that station, the "bed" of unionids started in about 2 m of water, while between 3 and 4 m, several hundred unionids were apparent. Zebra mussels tend to use unionids as a substrate for attachment. Large numbers of mussels can occlude the siphon apparatus of unionids, effectively killing them (Mackie, 1991; Gillis and Mackie, 1994). Severe negative impacts on *L. radiata* can therefore be expected as a result of the introduction of zebra mussels into Lake Couchiching.

In addition to the effects of zebra mussels on biological systems, zebra mussels have also been known to foul domestic and industrial water intakes. For those municipalities with drinking water intakes, the die-off of zebra mussels inside pipes can lead to taste and odour problems unrelated to those associated with increased algal growths (Katona, 1998). Treatment of water inside intake systems can control infestations beyond the point of intake. In municipal intakes, the use of alum to remove suspended solids also removes veliger larvae from the water column (Mackie and Kilgour, 1995). Low levels of chlorine added to intake water during settling periods (mid-summer) also prevents the settlement and attachment of mussels inside water intakes and distribution systems (Claudi and Mackie, 1994). Finally, zebra mussels do tend to be fairly abundant and when they die, their shells may wash up on shore. As a result, beaches can be less attractive for swimming and walking due to shell debris.

The ability of zebra mussels to filter and clarify lake water may be associated with changes in the taste and odour of drinking water taken from the lake. Increased light penetration should increase the production of macroflora, as well as benthic algae and bacteria. As discussed, growths of algal near the bottom of the lake have been observed.

The benthic fauna of Lake Couchiching generally reflect a slightly mesotrophic condition (Appendix J). This conclusion is based, in part, on the low numbers of tubificid worms. Tubificids are typically found in high numbers in eutrophic conditions (Howmiller, 1977; Milbrink, 1983). The conclusion of slight mesotrophy is also based on the complex of chironomid taxa found (Appendix J). The high proportion of Orthocladiinae chironomids (especially *Epoicocladius*), the Tanytarsini chironomids *Stempellina* and *Zavreliella* suggest relatively high water quality, since these taxa are sensitive to eutrophication (Saether, 1979; Bode, 1988). The most dominant chironomids included *Chironomus*, *Dicrotendipes, Paratendipes, Tanytarsus*, and *Procladius*. All but *Tanytarsus* are reasonably tolerant of eutrophic conditions, implying that the lake is at least to some degree eutrophied. Finally, mesotrophy can be assumed based on the abundances of organisms at all stations. Typically, oligotrophic lakes can support only up to about 2,000 benthic organisms $m^{-2}$ (Dermott, 1985; Dermott et al., 1986). In Lake Couchiching, numbers were generally in excess of about 20,000 $m^{-2}$ (Appendix J).

Spatial variation in benthic community composition in Lake Couchiching was apparent (Figure 15) but was unrelated to any of the chemical measurements made of water or sediments. As such, much of the observed variation in benthic community composition can be considered natural for the lake. The single physical factor that did tend to correlate with variation in benthic communities was depth. Although all stations were dominated by zebra mussels, benthic communities from the deep stations (5, 15, 17) had benthic communities with higher proportions of the phantom midge *Chaoborus punctipennis*. Two of these stations (5 and 15) also tended to have higher proportions of sphaeriid or fingernail clams (*Pisidium*), the snail *Helisoma anceps* and the chironomid *Paracladopelma*. The benthic fauna at Station 19 was unique. Station 19 was shallow (1.7 m depth) and near the inflow from Lake Simcoe. The benthic fauna there had relatively high proportions of isopods *(Lirceus lineata, Caecidotea racovitzae*), snails (*Viviparous georgianus*) and worms (*Limnodrilus clarapedianus*). All of these taxa are reasonably tolerant of high nutrient concentrations, but *L. lineata* tends to be found in cooler water. The fauna at this station are unique because it receives water from Lake Simcoe, which is a little cooler.

Chironomids, which are generally fairly tolerant of degraded water quality, were more dominant at Stations 8, 12, 16 and 18. The fauna at Station 18 was primarily composed of chironomids (midges; Figure 15). Chironomids may be prevalent at Station 8 because Robinson Creek discharges at that point. Benthic fauna at creek outlets can be expected to be somewhat unique because the discharges are a source of allochthonous organic matter. High proportions of the benthic fauna at Stations 16 and 18 may be reflecting impaired water quality at these locations.

# Overview of Environmental Quality

## 5. OVERVIEW OF ENVIRONMENTAL QUALITY

Lake Couchiching is a basic, hardwater lake. Primary production in the lake is limited by phosphorus, since water-borne phosphorus concentrations are low. In general, the lake can be classified as either oligotrophic or slightly mesotrophic based on good water clarity, low nutrient concentrations, and a suite of organisms (phytoplankton, zooplankton, benthos) that are typically associated with oligotrophic to slightly mesotrophic conditions. Bacterial (i.e., faecal coliform) levels in the lake were low, such that swimming is of high quality. Oligotrophic lakes are the most desirable from a recreational standpoint because of the high clarity. They also tend to support large sport fish because oxygen concentrations are high throughout the year, even in deep water. Mesotrophic lakes are characterized by moderate growth of algae and aquatic plants. They are suitable for the pursuit of water oriented recreational activities but have the potential to develop periodic algal blooms.

The lake has been exposed to anthropogenic sources of both metals and organic contaminants. Sediment core samples demonstrated significant increases in levels of chlorides, nutrients and metals in the most recently deposited sediments. These increases appear to be most localized near Orillia, and probably originate from urban runoff. Historically, sediment nutrients have been above PSQG LELs and are currently not above SELs. Water-borne nutrient concentrations are below concentrations that are typically associated with nuisance growths of algae. Metal levels are also generally below provincial water quality objectives and sediment LELs. Metal levels in water and sediments should therefore have no adverse effects on the biological systems of Lake Couchiching.

Contamination by organic compounds in Lake Couchiching is at low levels. Some marginal elevation of levels of oil and grease was demonstrated in more recent lake sediments, but these increases were associated with natural sources such as lipids and fats resulting from decomposing plant and animal matter. Atrazine was found at trace levels in water along the western shore. This herbicide originates from agricultural practices and is non-persistent. Observed trace amounts of atrazine do not pose ecological or human health risks. PAHs were detected at low concentrations in a few of the Lake Couchiching surficial sediment samples. PAHs were detected primarily in the south-west end of the lake near Orillia. With one minor exception, concentrations of the individual compounds, as well as total PAHs were below the respective LELs. Persistent organic contaminants including PCBs, organochlorine pesticides, phenoxy acid herbicides, chlorinated phenols, and chlorinated aliphatics and aromatics were not detected in any of the surface sediment samples. Organic contaminants in Lake Couchiching should therefore pose no ecological or human health risks.

Even though metal levels were low, there is still evidence that at least mercury is biologically available and biomagnifies in the food chain. Routine monitoring by the OMOEE (1997) shows that mercury levels in large specimens of smallmouth bass, largemouth bass, northern pike, walleye and yellow perch are elevated with consumption restrictions. Mercury levels in mid-lake surface sediments are elevated above historical levels, but remain below LELs.

The flora and fauna of Lake Couchiching are fairly typical for lakes in central Ontario. During the 1970s, macrophytes were dominated by Eurasian Water Milfoil. Since then, prevalence of this exotic species has declined. Another exotic, the zebra mussel (*Dreissena polymorpha*) is now a numerically dominant organism in the lake. Zebra mussels were shown in the 1997 survey to be dominant in both the benthos and plankton. Typically, zebra mussels adhere to hard substrate, but will attach to plants. With the macrophyte *Chara* prevalent at almost all stations, zebra mussels used the *Chara* as substrate. Zebra mussels present the most immediate environmental concern in the lake since it has the potential to not only alter biological processes in the lake, but to also interfere with domestic and industrial water uses, and recreation.

# Recommendations

# 6. RECOMMENDATIONS

## Recommendations

The third objective of this report is to provide recommendations concerning possible impacts associated with future development. With increasing development, there is the potential for alterations in water quality to occur. Some of the more significant sources of water quality impairment include:

i) soil erosion and sedimentation from construction activities
ii) increased contaminant, bacterial, and suspended solids loadings from storm-water runoff
iii) increased phosphorus loadings from future development (municipal sewage)
iv) streambank erosion in new developments
v) introduction of exotic species
vi) loss of aquatic habitat through shoreline development

Based on the predicted impacts of development and on the results of the survey, the following recommendations are made.

**Recommendation 1: Further confirmation and investigation of sites where impairment was demonstrated.**

Biological impairment was evident at Station 16 and at Station 18. Further confirmation and investigation of impairment at these two locations by the Ministry of the Environment is warranted.

**Recommendation 2: Implement appropriate management practices to minimize water quality impairment**

Water quality impairment from development can be minimized through proper planning, education and mitigation. In this regard, the Ministry of the Environment is conducting meetings with Municipalities, conservation authorities and consultants in Simcoe County.

**Recommendation 3: Develop a monitoring program to track long-term changes due to the trophic status of the lake.**

In order to assist area municipalities in making prudent planning decisions, the Ministry of the Environment will conduct periodic biological and chemical monitoring in Lake Couchiching.

# References

## 7. REFERENCES

Aiken, S.G., P.R. Newroth and I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum.* Canadian Journal of Plant Science, **59**:201-215.

Bode, R.W. 1988. Quality assurance workplan for biological stream monitoring in New York State. Stream Biomonitoring Unit, Bureau of Monitoring and Assessment, Division of Water, NYS Department of Environmental Conservation, Albany, NY.

CCME (Canadian Council of Ministers of the Environment). 1991. Canadian Water Quality Guidelines.

Carleton, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography, **22**:361-369.

Carter, S.R. 1979. The invasion and decline of *Myriophyllum spicatum* in a eutrophic Wisconsin lake. In, J.E. Breck, R.T. Prentki and O.L. Loucks (eds) Aquatic Plants, Lake Management and Ecosystem Consequences of Lake Harvesting. Conference proceedings, Madison, Wisconsin, February 146, 1979.

Chapman, L.J. and D.F Putnam, 1966. *The Physiography of Southern Ontario.* 2nd edition. Univ. of Toronto Press.

Claudi, R. and G.L. Mackie. 1993. Practical Manual for Zebra Mussel Monitoring and Control. Lewis Publishers, Boca Raton.

Cumming Cockburn Ltd., 1992. Estimated Monthly Flows and Exports of Total Nitrogen and Phosphorus from Lake Simcoe at Atherley. Report prep. for The Lake Simcoe Environmental Management Strategy Technical Committee. LSEMS Implementation Tech. Rep. No. Imp.B.12, April, 1992. 8 pp. + tables and appendix.

David, S.M., K.M. Somers, R.A. Reid, R.J. Hall and R.E. Girard, 1998. Sampling Protocols for the Rapid Bioassessment of Streams and Lakes using Benthic Macroinvertebrates. Ontario Ministry of Environment and Energy, Aquatic Sciences Section report. Dorset, Ontario.

Dermott, R.M. 1985. Benthic fauna in a series of lakes displaying a gradient of pH. Hydrobiologia, **128**:31-38.

Dermott, R.M., J.R.M. Kelso and A. Douglas. 1986. The benthic fauna of 41 acid sensitive headwater lakes in north central Ontario. Water, Air and Soil Pollution, **28**:283-292.

Dermott, R.M., J. Mitchell, I. Murray and E. Fear. 1993. Biomass and production of zebra mussels (Dreissena polymorpha) in shallow waers of northeastern Lake Erie. In, T.F. Nalepa and D.W. Schloesser (eds), Zebra Mussels, Biology, Impacts, and Control. pp. 399-414.

Fanslow, D.L., T. Nalepa, G. Lang. 1995. Filtration rates ofthe zebra mussel on natural seston from Saginaw Bay, Lake Huron. Journal of Great Lakes Research, **21**:489-500.

Fassett, N.C. 1957. A Manual of Aquatic Plants. The University of Wisconsin Plants. 405 pp.

Gemza, A., 1995a. Spatial and temporal water quality trends in Severn Sound, Georgian Bay, since the introduction of phosphorus control guidelines: nutrients and phytoplankton, 1973 to 1991. Water Quality Research Journal of Canada, **30(4)**:565-591.

Gemza, A., 1995b. Zooplankton seasonal dynamics and community structure in Severn Sound, Lake Huron. Water Quality Research Journal of Canada, **30(4)**:673-691.

Gillis, P. and G.L. Mackie. 1994. Impact of the zebra mussel, *Dreissena polymorpha*, on populations of Unionidae (Bivalvia) in Lake St. Clair. Canadian Journal of Zoology, **72**:1260271.

Griffiths, R.W., 1993. Effects of zebra mussels (*Dreissena polymorpha*) on the benthic fauna of Lake St. Clair. T.F. Nalepa and D.W. Schloesser (eds), *Zebra Mussels: Biology, Impacts and Control*. Lewis Publishers, Boca Raton, Florida. pp. 415-437.

Health and Welfare Canada. 1983. Guidelines for Canadian Recreational Water Quality. Federal-Provincial Advisory Committee on Environmental and Occupational Health, Ottawa.

Howell, E.T., C.H. Marvin, R.W. Bilyea, P.B. Kauss and K. Somers, 1996. Changes in environmental conditions during Dreissena colonization of a monitoring station in eastern Lake Erie. Journal of Great Lakes Research, **22(3)**:744-756.

Howmiller, R.P. and M.A. Scott. 1977. An environmental index based on relative abundance of oligochaete species. Journal of the Water Pollution Control Federation, **49:**809-815

Hunter, C. and B. McGee, 1994. Survey of Pesticide Use in Ontario, 1993. Estimates of Pesticides Used on Field Crops, Fruit and Vegetable Crops, Provincial Highway Roadsides, and by Licensed Pesticide Applicators. Ontario Ministry of Agriculture, Food and Rural Affairs, Policy Analysis Branch report, November 1994. 31 pp.

Jones, M. and D. Veal, 1972. Aquatic Plant Growths in Lake Couchiching. Ontario Ministry of the Environment, Water Resources Division report. Toronto, Ontario. 29 pp. + appendix.

Katona, G.Z. 1998. Phytoplankton and water quality study of Lake Couchiching to identify causes of taste and odour problems in Orillia drinking water supply. Prepared for the City of Orillia. Report AWM - 039.

Kilgour, B.W., R.C. Bailey, E.T. Howell and W.M. Morton. 1995. Nearshore benthos of Lake Ontario, 1981 and 1991. Final report prepared by Water Systems Analysts for the Ontario Ministry of Environment and Energy.

Klemer, A. and J. Barko 1991. Effects of mixing and silica enrichment on phytoplankton seasonal succession. Hydrobiologia **210:**17181.

Lake Simcoe Conservation Authority, Ministry of Natural Resources, Ministry of Environment and Energy, and Ministry of Agriculture, Food and Rural Affairs. 1995. Lake Simcoe: Our Waters, Our Heritage. Lake Simcoe Environmental Management Strategy, Implementation Program, Summary of Phase I Progress and Recommendations for Phase II, November 1995.

Lowe, R.L. and R.W. Pillsbury. 1995. Shifts in benthic algal community structure and function following the appearance of zebra mussels (*Dreissena polymorpha*) in Saginaw Bay, Lake Huron. Journal of Great Lakes Research, **21**:558-566.

Mackie, G.L. 1991. Biology of the exotic zebra mussel, *Dreissena polymorpha*, in relation to native bivalves and its potential impact in Lake St. Clair. Hydrogiologia, **219**:251-268.

Mackie, G.L. and B.W. Kilgour. 1995. Efficacy and role of alum in removal of zebra mussel veliger larvae from raw water supplies. Water Research, **29**:731-744.

Marchant, R. 1989. A subsampler for samples of benthic invertebrates. Bulletin of the Australian Society of Limnology, **12**:49-52

Milbrink, G. 1983. An improved environmental index based on the relative abundance of oligochaete species. Hydrobiologia, **102**:89-97.

Newmaster, S.G., A.G. Harris, and L.J. Kershaw. 1997. Wetland Plants of Ontario. Lone Pine Publishing, Edmonton. 240 pp.

Nicholls, K.H., E.C. Carney and G.W. Robinson, 1977. Phytoplankton of an inshore area of Georgian Bay, Lake Huron, prior to reductions in phosphorus loading. Journal of Great Lakes Research, **3(1-2)**:79-92.

OMOE (Ontario Ministry of the Environment). 1978. Mercury in the Lake Simcoe aquatic environment. Water Resources Branch.

OMOE (Ontario Ministry of the Environment), 1989. A Guide to the Collection and Submission of Samples for Laboratory Analysis. Laboratory Services Branch, Etobicoke, Ontario. 81 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1993. The Determination of Trace Metals in Potable Waters by ICP-MS. DWATER-E3051A. Laboratory Services Branch Quality Management Office, July 9, 1993. 43 pp.

OMOEE. 1994a. The Determination of Trace Metals in Sediments by the Spectro Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES). HMARSOIL-E3062A. Laboratory Services Branch Quality Management Office, March 28, 1994. 45 pp.

OMOEE. 1994b. Water Management Policies, Guidelines, Provincial Water Quality Objectives of the Ministry of Environment and Energy. July, 1994. Toronto, Ontario. 21 pp. + table + appendix.

OMOEE. 1994c. The Determination of Polychlorinated Biphenyls (PCBs), Organochlorines (OCs) and Chlorobenzenes (CBs) in Soil and Sediments by Gas Liquid Chromatography-Electron Capture Detection (GLC-ECD). PSAOC-E3270A. Laboratory Services Branch Quality Management Office, July 18, 1994. 37 pp.

OMOEE. 1994d. The Determination of Polynuclear Aromatic Hydrocarbons (PAH) in Soil and Sediments by Gel Permeation Chromatography-High Performance Liquid Chromatography (GPC-HPLC). PSAPAH-E3350A. Laboratory Services Branch Quality Management Office, July 20, 1994. 28 pp.

OMOEE. 1995a. The Determination of Total Carbon in Soil and Sediments by the Leco Carbon Analyzer. CARBONTC-E3142A. Laboratory Services Branch Quality Management Office, July 1, 1995. 19 pp.

OMOEE. 1995b. The Determination of Moisture Content, RST, RSTA, and LOI in Sediments by Gravimetry. PHYSOLID-E3139A Laboratory Services Branch Quality Management Office, October 16, 1995. 18 pp.

OMOEE. 1995c. The Determination of Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans in Soil and Sediment by GC-MS. PSAFD-E3151B. Laboratory Services Branch Quality Management Office, November 25, 1995. 34 pp.

OMOEE. 1997. Guide to Eating Ontario Sport Fish. 1997998. Environmental Monitoring and Reporting Branch, Biomonitoring Section.

OMNR (Ontario Ministry of Natural Resources). 1985. Guide to taxonomic standards for the identification of Ontario freshwater invertebrates. Draft report, 1985.

Pace, M.L. 1986. An empirical analysis of zooplankton community size structure across lake trophic gradients. Limnology and Oceanography, **31**:45-55.

Persaud, D., R. Jaagumagi and A. Hayton, 1993. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario. Ontario Ministry of Environment and Energy, Standards Development Branch and Environmental Monitoring and Reporting Branch. August, 1993, reprinted September, 1994. Toronto, Ontario. 24 pp. + 3 figs.

Provonsha, A.V. 1990. A revision of the genus Caenis in North America (Ephemeroptera: Caenidae). Transactions of the American Entomological Society, **116**:801-884.

Quigley, M..A. and J. Robbins 1986. Phosphorus release processes in nearshore southern Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences, **43**:1201207.

Rappe, C., 1994. Dioxin, patterns and source identification. Fresenius Journal of Analytical Chemistry, **348**:63-75.

Redshaw, C.J., C. Mason, C. Hayes, and R. Roberts. 1990. Factors influencing phosphate exchange across the sediment water interface of eutrophic reservoirs. Hydrobiologia **192**:233-245.

Resh, V.H. and E.P. McElravy. 1993. Contemporary quantitative approaches to biomonitoring using benthic macroinvertebrates. In, D.M. Rosenberg and V.H. Resh (eds), Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman & Hall, New York.

Reynoldson, T.B., and D.M. Rosenberg. 1996. Sampling strategies and practical considerations in building reference data bases for the prediction of invertebrate community structure. In, R.C. Bailey, R.H. Norris and T.B. Reynoldson (eds), Study Design and Data Analysis in Benthic Macroinvertebrate Assessments of Freshwater Ecosystems Using a Reference Site Approach, Technical Information Workshop, North American Benthological Society, 44th Annual Meeting, Kalispell, MT.

Saether, O.A. 1979. Chironomid communities as water quality indicators. Holarctic Ecology, **2**:65-74.

Schloesser, D.W. 1986. A Field Guide to Valuable Underwater Plants of the Great Lakes. U.S. Fish and Wildlife Service, Great Lakes Fishery Laboratory, Ann Arbor, Michigan, and Cooperative Extension Serive, Michigan State University, East Lansing, Michigan. Contribution 644, Great Lakes Fishery Laboratory, U.S. Fish and Wildlife Service, Ann Arbor Michigan.

Schloesser, D.W. and B.A. Manny. 1984. Distribution of Eurasian Water Milfoil, *Myriophllum spicatum*, in the St. Clair-Detroit River system in 1978. Journal of Great Lakes Research, **10**:322-326.

Shannon, C.E. and W. Weaver. 1949. *The Mathematical Theory of Communication.* The University of Illinois Press. Urbana, IL.

Smith, V.H. 1986. Low nitrogen to phosphorus ratios favor dominance of blue-green algae in lake phytoplankton. Canadian Journal of Fisheries and Aquatic Sciences, **43**:14853.

Stoeckmann, A.M. and D.W. Garton. 1997. A seasonal energy budget for zebra mussels in western L. Erie. Canadian Journal of Fisheries and Aquatic Sciences, **54**:2743-2751.

Stoermer, E.F. and E. Theriot 1985. Phytoplankton distribution in Saginaw Bay. Journal of Great Lakes Research,**11**:13242.

Vollenweider, R.A., M. Munawar and P. Stadelman, 1974. A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. Journal of the Fisheries Research Board of Canada, **31**: 739-762.

Wetzel, R.G., 1983. *Limnology,* 2nd edition. W.B. Saunders Co., Toronto.

Wile, I., G. Hitchin and G. Beggs. 1979. Impact of mechanical harvesting on Chemung Lake. In, J.E. Breck, R.T. Prentki and O.L. Loucks (eds) Aquatic Plants, Lake Management and Ecosystem Consequences of Lake Harvesting. Conference proceedings, Madison, Wisconsin, February 14-16, 1979.